Missouri
Water Supply Study

By

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MISSOURI
DEPARTMENT OF
NATURAL RESOURCES

FORWARD

The Missouri Department of Natural Resources' Water Resource Center and Public Drinking Water Branch have the responsibility to assist state residents by assuring them of adequate and safe water supply. The purpose of this information is to ensure availability of water information for effective decision-making by communities and department program managers. In addition, it is expected to be used to determine and allocate existing water supplies. The scope of this study primarily addresses surface water supplies to cities and communities that are expected to experience water shortages during an extended drought. Surface water supplies consist of lakes, rivers and streams and in many cases combinations of both.

PREFACE

This data and service conditions of the analyzed systems were accurate at the time of study but may not reflect present day water use or system capability due to modifications or changes in source water.

This 2010 water supply report is a result of the state's water resource law water planning mandates and done under the direction of the Missouri Drought assessment committee. This report and several previous compact disc versions since year 2000 have examined communities at risk and their ability to sustain themselves during drought. Many of these water supplies had only months of water supply assured during recent droughts of 1999-2000 and 2002-2004. Most of the communities are located in the northern and western areas of Missouri. These areas are groundwater poor and dependent upon surface water supplies. Four community supplies that draw most of their water supplies from streams in northern and southern Missouri were also examined for firm yield capability. This study is not a complete evaluation of all communities at risk of depletion of water. Updates to this 2010 Water Supply Report are expected and will be produced by compact disc.

The authors determined that a hard cover edition was needed to better illustrate to a wider audience the critical water quantity needs of many marginal water supplies in the state.

CONTENTS

Lake Studies

Streams and River Analysis

Water Supply Projections

Appendices

List of Tables

List of Figures

Figures

3. Bowling Green

4. Breckenridge

5. Brookfield

6. Bucklin

7. Butler

8. Cameron

9. Concordia

10. Creighton

11. Dearborn

12. Drexel

13. Fayette

14. Garden City

15. Green City

16. Hamilton

17. Harrison County Rural Water Dist. #1

18. Harrisonville

19. Higginsville

20. Holden

21. Ironton

22. Jamesport

23. King City

24. Kirksville

25. Lake Viking

26. Lamar

27. Little Otter

28. Marceline

29. Maysville

30. Memphis

31. Middle Fork

32. Milan

33. Moberly

34. Monroe City

35. Mozingo Creek Reservoir (Maryville)

36. Ridgeway

37. Sedalia

38. Shelbina

39. Unionville

40. Vandalia

Stream and River Analysis Figures

45. Joplin: Shoal Creek

50. Perryville: Saline Creek

60. Poplar Bluff: Black River

70. Trenton: Thompson River

Water Supply Projections

INTRODUCTION

This report was prepared by Missouri Department of Natural Resources to address water supply needs and distribution as a result of extremely dry weather during the drought beginning in 1999 and extending into year 2004. Reservoirs were surveyed by USGS to determine the remaining storage of water for use by cities, communities, and rural water districts. This data is used for drought planning in establishing a network of available water supplies to be used to distribute to needed locations in north and west central Missouri where water needs are met by surface sources. This report is not meant to be used as a regulatory manual.

Surface water supplies studied and contained in this report are:

Water Supply Systems

1. Adrian
2. Bethany
3. Bowling Green
4. Breckenridge
5. Brookfield
6. Bucklin
7. Butler
8. Cameron (4 lakes)
9. Concordia (E.A. Pape Lake)
10. Creighton
11. Dearborn
12. Drexel
13. Fayette (2 lakes)
14. Garden City (2 lakes)
15. Green City
16. Hamilton
17. Harrison County Rural Water District #1
18. Harrisonville
19. Higginsville
20. Holden
21. Ironton
22. James Port
23. King City (4 lakes)
24. Kirksville
25. Lake Viking
26. Lamar
27. Little Otter
28. Marceline
29. Maysville
30. Memphis (Lake Show Me and Old City Lake)
31. Middle Fork Grand (Stanberry)
32. Milan
33. Moberly
34. Monroe City
35. Mozingo
36. Ridgeway
37. Sedalia
38. Shelbina
39. Unionville
40. Vandalia

Also, this report contains Stream Flow analysis to selected cities obtaining their water supply from rivers and streams. These streams are:

1. Black River at Poplar Bluff
2. Saline Creek at Perryville
3. Shoal Creek at Joplin
4. Thompson River at Trenton

In addition, staff gauges were installed in five lakes. The gauges will aid in making estimates of remaining water supplies and projections during drought periods. These lakes are:

1. Butler
2. Eagleville (Harrison County Rural Water District #1)
3. Hamilton
4. Marceline
5. Monroe City (Rte. J Lake)

ACKNOWLEDGEMENTS

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The United States Geological Survey staff located in Rolla, Missouri made field surveys of lakes.

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EXECUTIVE SUMMARY

Missouri Department of Natural Resources Water Resources Program Surface Water Supply Staff has prepared an analysis of 44 communities' water systems within Missouri. These include 40 lake systems and four systems using streams as their main water supply source. These systems are mostly in the north and western part of the state. Many of the cities and water supply districts in northern and western Missouri must obtain their supplies from surface water sources in areas where there is either a lack of available wells, poor water quality or both. Two of the southeastern streams are the exception. They are Black River at Poplar Bluff and Saline Creek at Perryville.

The objective of this water supply study is to provide technical hydrology and water resource engineering assistance to communities on how to allocate their water supplies during the critical drought of record in order to satisfy their needs during an extended multi-year dry episode. How we manage our water greatly effects the well being and economic stability of the area.

Scenario illustrations are presented for several communities to assist local decision-makers in allocating scarce water supplies. Projecting these scenarios upon current water demands through the most severe drought of record by placing optimum demands upon the reservoirs, streams, and off channel storage facilities in area will assist community leaders in determining if additional water supplies must be found or developed to avert water supply emergencies.

The 1950's drought is the most severe extended drought of record for Missouri. The time period 1951 through 1959, the “drought of record” was used as a base for determining the adequacy of present reservoir water supply capability.

Several of the examined water supply systems are from a collection of surface water sources, which can include several small lakes in series or tandem, often supplemented by in-stream diversion pumps. These analyses were made for some of the most critical supplies. Cities usually use two sources to supply their needs. These sources are lakes and flowing streams. Water stored in lakes comes from rainfall runoff to the lakes. Many of the lakes are too small in size and drainage area to satisfy local needs. As a result, the supply provided by the lakes must be supplemented by other sources. A common practice is to pump from streams into the lakes during high stream flows in an attempt to keep water levels in lakes near full. During droughts one can expect the streams to dry up or stream flow to be so low that pumping cannot be achieved. Basic engineering programs were used to study lake capacities and stream flows.

Staff gages are planned to be or have been installed on five of the lakes. By using these reservoir stage gages and with the analysis of historical droughts, supply projections can be made. We also produced frequency of depletion type charts. These charts can assist engineers to assess water needs and distribution. If an additional step is taken by the local communities to monitor supplies the local operators can project for themselves their remaining storage to empower public works directors on how to allocate existing water supplies.

Because of the gradual increases in demand for water, these charts will also assist in determining the urgency of providing new reservoirs and additional water storage facilities.

Tables one and two show the dependability of water supplies for each system. Not all systems could withstand a drought such as the one in the 1950's with their present demands.

MISSOURI WATER SUPPLY STUDIES

Summary of Lake Analysis

CITY	Lake Name	Drainage area Acres	Drainage area Sq.Mi.	Annual Demand Gallons	Annual Demand mgd	Optimum Yield from Lake mgd	Optimum Yield with Pumping mgd	Year of Analysis	Lake Storage Acre-Ft	Comments
Adrian	City Lake	517	0.81	135,999,600	0.373	0.050	0.492	2003	290	
Bethany	West Fk Big Ck-C1	11,000	17.20	80,300,000	0.220	0.590	NA		1,095	Water is pumped to New Lake
	Bethany New Lake	750	1.17		0.175	0.175	NA		499	Water is pumped to Old Lake
	Bethany Old Lake	218	0.34		0.051	0.051	NA		162	Water to treatment plant from Old Lake
	Supply System	11,975	18.71	133,095,000	0.365	0.816	NA	2002	1,754	
Bowling Green	East Lake	803	1.25	129,870,000	0.356	0.363	NA		1,240	Pump from East To West Lake and return
	West Lake	809	1.26	86,580,000	0.237	0.237	NA		460	for maximum use of runoff into lakes.
	Supply System			216,450,000	0.593	0.593	NA	2005		
Breckenridge	City Lake	416	0.65	21,535,000	0.059	0.052	NA	2004	140	
Brookfield	City Lake	650	1.02			0.207	0.230		2,070	Lake only
	City Lake + stream					NA	0.617			Lake plus West Yellow Creek
Total	Supply System			244,845,000	0.671	NA	0.671	2000		Lake, West Yellow Creek & holding basins
Bucklin	City Lake	300	0.47	31,025,000	0.085	0.046	0.085	2007	157	
Butler	City Lake	1990	3.11	368,562,000	1.010	0.270	1.010	2001	749	Lake & Marais Des Cygnes River
Cameron	Grindstone Res.	13382	20.91	273,750,000	0.750	0.850	NA		2,019	Water is pumped to lake 3
	Reservoir #1	1050	1.65			0.060	NA		103	Water gravity flows to Lake 3
	Reservoir #2	1150	1.80			0.130	NA		320	Water gravity flows to Lake 3
	Reservoir #3	1100	1.73			0.320	NA		938	Water to treatment plant
	Supply System	16682	26.09	567,450,000	1.554	1.360	NA	2013	3,380	
Concordia	E.A. Pape Lake	5425	8.48	180,424,870	0.494	0.839	NA	2002	2,740	Historical Demand
				474,500,000	1.300	1.330	1.330	2002		Increase Demand
Creighton	City Lake	630	0.99	10,220,000	0.028	0.066	NA	2003	113	
Dearborn	City Lake	350	0.55	22,724,000	0.062	0.010	NA	2000	52	Dearborn now buys from K.C.
Drexel	City Lake #1	2989	4.67	0	0	0	NA			Not used for water supply
	City Lake #2	535	0.84	37,522,000	0.103	0.119	NA		345	Lakes not in series
	Supply System	3524	5.51	37,522,000	0.103	0.119	NA	2003		
Fayette	D.C. Rogers Lake	2490	3.89	153,300,000	0.420	0.190	NA	2007	2,520	Drainage area includes Fayette lake
	Fayette Lake	1254	1.96	NA	NA	NA	NA		717	In series upstream of D.C.Rogers lake
Garden City	Cities New Lake	430	0.67	29,889,810	0.082	0.182	NA	2004	441	
	Cities Old Lake	109	0.17	20,311,090	0.056	0.069	NA	2004	177	
	Supply System	539	0.84	50,200,900	0.138	0.251	NA		618	

MISSOURI WATER SUPPLY STUDIES
Summary of Lake Analysis

CITY	Lake Name	Drainage area Acres	Drainage area Sq.Mi.	Annual Demand Gallons	Annual Demand mgd	Optimum Yield from Lake mgd	Optimum Yield with Pumping mgd	Year of Analysis	Lake Storage Acre-Ft	Comments
Green City	City Lake	800	1.25	66,612,500	0.183	0.149	NA	2000	428	
Hamilton	City Lake	1142	1.78	94,900,000	0.260	0.190	0.260	2000	896	Lake and Marrowbone Creek
Harrison Co.	Lake	3009	4.70	30,660,000	0.086	0.044	NA	2003	140	
PWSD#!	Lake and Basin	0	0.00			0.087	NA			Storage basin added for volume
Harrisonville	City Lake	9523	14.88	511,000,000	1.400	1.540	NA	2007	6,990	
Higginsville	City Upper Lake	1730	2.70	0	0.000	0	NA		128	For sediment control
	City Lower Lake	1700	2.66	337,125,000	0.924	0.462	1.310	2002	1,462	Pump from Mo.River to lake
Holden	City Lake	2572	4.02	91,250,000	0.250	0.567	NA	2003	3,810	
Ironton	Shepherd Mountain	2624	4.10	73,000,000	0.200	0.226	NA	2007	186	Drainage area includes Snow Hollow lake
	Snowhollow Lake	500	0.78	0	0.000	NA	NA		321	Upstream of Shepherd Mountain lake
Jamesport	City Lake	900	1.41	21,900,000	0.060	0.069	NA	2000	163	
King City	South Lake	550	0.86		0.074	0.078	NA	2000	417	
	North upper lake	60	0.09		0.005	0.005	NA		39	
	North middle Lake	240	0.38		0.007	0.008	NA		65	
	North lower lake	210	0.33		0.039	0.042	NA		332	
	Supply System	1060	1.66	45,625,000	0.125	0.133	NA	2000	853	
Kirksville	Forest Lake	9415	14.71	1,058,634,000	2.900	3.530	NA	2005	12,500	Kirksville total demand
	Hazel Creek Lake	6165	8.07	1,058,634,000	2.900	1.954	NA	2005	8,680	
Lake Viking	Private Lake	9040	14.13	18,250,000	0.050	2.460	NA	2006	12,000	
Lamar	City Lake	3050	4.77	175,144,800	0.480	0.427	NA	2002	1,582	Also use one well
	Well					0.430	NA			(2)600 GPM pumps
	Supply System					0.587	NA			Assume can pump 1/2 time
Little Otter	County Lake	4820	7.53	438,000,000	1.200	1.200	NA		6,624	Cooperation with NRCS PL-566 program
Marceline	Newer City Lake	2388	3.73	163,420,300	0.448	0.412	NA	2003	1,990	
	Older City Lake	271	0.42	0	0.000	0.060	NA		462	Old Lake not used or surveyed
	Supply System	2659	4.15	163,420,300	0.448	0.472	NA	2003	2,452	
Maysville	Willowbrook Lake	3740	5.84	44,927,000	0.123	0.310	NA	2000	784	
	South Lake	140	0.22		0.000	0.020	NA		75	
	West Lake	2050	3.21		0.000	0.120	NA		250	
	Supply System	5930	9.27	44,927,000	0.123	0.450	NA	2006	1,109	

MISSOURI WATER SUPPLY STUDIES
Summary of Lake Analysis

CITY	Lake Name	Drainage area Acres	Drainage area Sq.Mi.	Annual Demand Gallons	Annual Demand mgd	Optimum Yield from Lake mgd	Optimum Yield with Pumping mgd	Year of Analysis	Lake Storage Acre-Ft	Comments
Memphis	Lake Show Me	1700	2.66	153,300,000	0.420	0.780	NA	2002	4,125	
	Old City Lake	965	1.51	0	0.000	0.095	NA	2001	220	Downstream of New Lake
	Total	2665	4.17	153,300,000	0.420	0.875	NA	2002	4,345	
Middle Fork	Lake	4037	6.30	127,750,000	0.350	0.381	NA	2000	915	Includes Stanberry
Milan	Elmwood Lake	4100	6.41	602,250,000	1.650	0.737	1.650	2000	2,503	
	Golf Course Lake	680	1.06	0	0.000	0.116	0.116	2000	555	
	Supply System	4780	7.47	602,250,000	1.650	0.854	1.766	2000		Lake and Stream
	Shatto	170	0.26	0	0	0.083	NA	2000	662	Private Lake - Not used for water supply
Moberly	Sugar Creek Lake	7170	11.05	561,159,100	1.537	1.200	1.540	2003	5,250	
Monroe City	Rt. J Lake	5250	8.20	152,701,000	0.418	1.010	NA	2002	1,246	
Mozingo	Maryville Lake	13,390	20.92	700,800,000	1.920	2.900	NA	2001	17,520	Cooperation with NRCS PL-566 program
Ridgeway	Rock House Lake	5723	8.94	13,991,000	0.038	0.246	NA	2003	461	
Sedalia	Spring Fork Lake	7027	10.98	990,657,900	2.714	1.059	NA	2002	1,249	
Shelbina	Lake	1542	2.41	127,249,000	0.349	0.273	0.360	2001	406	Pump from Salt River
Unionville	Lake Mahoney	1900	2.97	139,500,000	0.382	0.283	NA	2004	620	Uses Lake Thunderhead
	Lake Thunderhead	14700	22.96	0		3.361	NA	2004	15,400	Private lake not designed for water supply
Vandalia	Vandalia Lake	3666	5.73	94,535,000	0.259	0.330	NA	2005	317	

Table 1

MISSOURI WATER SUPPLY STUDIES
Low Stream flows

CITY	STREAM	Drainage Area sq.mi.	Annual Water use Total gallons	Annual Water use Daily use mgd	7-day Q10 Low flows cfs	7-day Q10 Low flows mgd	1 year In 50 Lowest Mean monthly Low flows cfs	1 year In 50 Lowest Mean monthly Low flows mgd	Year 2000 Mean Base Flow cfs	Comments
Joplin	Shoal Creek	427.0	3,949,175,941	10.82	43	27.75	34.0	21.94	226	No off channel storage
Perryville	Saline Creek	55.8	289,448,000	0.79	1	0.65	0.9	0.58	18	No off channel storage Use wells
Poplar Bluff	Black River	1245.0	1,122,486,000	3.08	216	139.41	254.0	163.94	603	No off channel storage
Trenton	Thompson	1670.0	694,520,000	1.90	9	5.81	7.5	4.84	55	Off channel storage

cfs in cubic feet per second
mgd in million gallons per day

Table 2

Introduction to Lake Analysis

These analyses were made for the drought of record, which was through the 1950's. At least two conditions are presented in all cases. The first run was made with current demand and the second was to optimize that demand to establish the firm yield. Other runs were made if necessary, such as effects of different schemes of pumping from a creek. If pumping from a stream was incurred, additional runs were made to evaluate effects of pumping.

USDA's Natural Resource Conservation Service reservoir operations computer program "RESOP" was used to make each evaluation. Computations are in one-month increments and represent end of month results. The "RESOP" program uses:

1. Lake volume and surface area
2. Rainfall
3. Runoff
4. Lake Evaporation
5. Seepage
6. Demand or water usage
7. Other inflow such as pumping from a stream.

Sources of data used to evaluate remaining storage in each reservoir are:

- Reservoir Storage - Reservoirs were surveyed for remaining available storage by the USGS from year 2000 to 2004.
- Time Period - The analysis for drought effects was selected to be the 1950's. This was the longest and most severe drought of record.
- Rainfall - Rainfall for each water supply lake was the nearest NOAA weather station. If there were missing days in the data, then the next nearest station was used to fill in the gaps.
- Runoff - Regional monthly runoff from nearest stream gages were used. If the runoff did not look to be reasonable, i.e. Runoff greater than rainfall for a certain month, adjustments were made to the runoff by examining each individual rainfall event for that month. To make the runoff determination, five-day rainfall was used to estimate the anticedent moisture. The NRCS cover complex number was used to estimate runoff for each storm. See appendix "A" for an explanation.
- Evaporation - The nearest NOAA weather station with pan evaporation data was used. Pan evaporation was then adjusted to Lake Evaporation.
- Seepage - Seepage was estimated based on experience. In north Missouri seepage is very low.
- Demand - Demand is the amount of water available for consumptive uses. This value comes from community records.
- Other - Other is used to identify other inflow or outflow such as pumping from a stream.

"RESOP" is a DOS program. The users manual and software for the
“RESOP" program is not included in this report but are available on CD upon request.

Missouri drinking water supplies studied and dates surveyed.

Water Supply Lake		Date of Lake Bathymetry Survey
1. Adrian		April 2003
2. Bethany	2 City Lakes	(Not Mapped)
	Big Creek Lake C-1	(Map available at NRCS)
3. Bowling Green	East Lake	February 2005
	West Lake	February 2005
4. Breckenridge		April 2004
5. Brookfield		July 2000
6. Bucklin		March 2007
7. Butler		April 2001
8. Cameron	Reservoir GLM-A2	July 2013
	3 City Reservoirs	July 2013
9. Concordia	E.A. Pape Lake	June 2002
10. Creighton		June 2003
11. Dearborn		June 2000
12. Drexel		June 2003
13. Fayette	D.C. Rogers Lake	March 2007
	Fayette Lake	(Not Surveyed)
14. Garden City	New Lake	April 2004
	Old Lake	April 2004
15. Green City		July 2000
16. Hamilton		July 2000
17. Harrison County Rural Water Dist. #1		May 2003
18. Harrisonville		March 2007
19. Higginsville		June 2002
20. Holden		June 2003
21. Ironton	Shepherd Mountain Lake	July 2007
	Snowhollow Lake	July 2007
22. James Port		July 2000
23. King City	South Lake	July 2000
	Lower North Lake	(Not Shown)
	Middle North Lake	(Not Shown)
	Upper North Lake	(Not Shown)
24. Kirksville	Forest Lake	March 2005
	Hazel Creek Lake	March 2005
25. Lake Viking		March 2006
26. Lamar		May 2002
27. Little Otter Creek Lake		(Map available at NRCS)
28. Marceline		May 2003
29. Maysville	Willowbrook Lake	July 2000
	Maysville South Lake	March 2006
	Maysville West Lake	March 2006
30. Memphis	Lake Show Me	June 2001
	Old City Lake	June 2002
31. Middle Fork Grand River		July 2004
32. Milan	Elmwood Lake	June 2000
	Golf Course Lake	June 2000
	Shatto Lake	July 2000
33. Moberly	Sugar Creek Lake	Dec. 2003
34. Monroe City	RTE "J" Lake	June 2004
35. Mozingo Creek		(Map available at NRCS)
26. Ridgeway		May 2003
27. Sedalia	Spring Fork Lake	April 2002
29. Shelbina		June 2001
39. Unionville	Lake Mahoney	April 2004
	Lake Thunderhead	April 2003
40. Vandalia		February 2005

Adrian Reservoir System

Water Supply Study – Adrian, Missouri
Drought Assessment Analysis

I. Overview

The Adrian reservoir system (figure 1.1) is located east of the City of Adrian in northern Bates County, Missouri. The reservoir system is the primary source of drinking water for the City of Adrian and Bates County PWSD (Public Water Supply District) # 5, which purchases all of its drinking water from Adrian. The combined population served by the Adrian reservoir system is approximately 4,000 with an average consumption of 0.588 million gallons per day (mgd) according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

The Adrian reservoir system consists of a lower (primary) lake and a small upper lake that serves as a sediment control basin for the primary lake. Since 1938, the Adrian reservoir system has been supplemented with water diverted from the South Grand River. Water is only diverted from the South Grand River if stream flow exceeds 3 cubic feet per second (cfs) due to in-stream flow needs for water quality concerns. Demand on the Adrian Reservoir in 2000 was approximately 0.373 million gallons per day. The calculated firm yield from the reservoir is only 0.0495 million gallons per day - to meet the demand of 0.373 million gallons per day, raw water is pumped from the South Grand River into the reservoir. Historical water demand on the Adrian Reservoir is illustrated in figure 1.2.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program. Additional models were used to assess stream flow data for the South Grand River; however, these models are not described here. The stream flow analysis for the South Grand River is described in the Stream Analysis section of this report.

Two scenarios were analyzed for the Adrian reservoir system using the RESOP model:

1. The first scenario assesses the water budget for the reservoir with no additional sources of water (no diverting from the South Grand River). An analysis of ‘Normal’ demand (actual demand from 2000) was applied to the reservoir during the drought of record to assess potential water deficits. A second analysis for ‘Optimum’ demand was performed to determine the firm yield from the reservoir without additional water sources - this value represents the viable quantity of water available. Figure 1.3.a illustrates the relationship between these two curves - when actual demand is applied to this scenario the reservoir is emptied completely and would not be capable of supplying water to meet demand. The firm yield is insufficient to meet demand.

2. The second scenario analyzes ‘Normal’ demand and ‘Optimum’ demand for the Adrian reservoir system when additional water is diverted to the reservoir from the South Grand River (figure 1.3.b). A stream flow analysis was performed on the South Grand River to estimate the number of days per year that stream flow would exceed 3 cfs and allow for pumping. Based on this analysis, it was estimated that water diverted from the South Grand River to the reservoir would allow Adrian to meet the 2000 demand of 373,000 gallons per day if the pump operates two-thirds of the time that stream flow exceeds 3 cfs. If water is diverted the entire time that stream flow is sufficient in the South Grand River, Adrian was

estimated to be capable of producing 492,000 gallons per day (with a maximum pump rate of 500 gallons per minute).

Figure 1.3.c illustrates the degree of water loss due to evaporation from the sediment control basin.

II. Drought Assessment Summary

The Adrian reservoir system without additional sources of water is not sufficient to meet demand. The 2000 demand of 0.373 mgd, when applied to the reservoir during the drought of record (with no other sources of water) would have resulted in water deficits November 1952 through January 1955, July 1955 through March 1957, February 1958, and August 1959 through December 1959. The estimated firm yield from the Adrian reservoir system without supplementary supplies is 49,500 gallons per day.

The Adrian reservoir system is capable of meeting and exceeding the 2000 demand of 373,000 gallons per day with additional water diverted to the reservoir from the South Grand River. The 2000 demand of 0.373 gpd can be met if water is diverted from the river two-thirds of the time that stream flow exceeds 3 cfs (calculations and estimates are based on additional stream flow analysis models and a maximum pump rate of 500 gallons per minute). If water is diverted to the reservoir at the maximum pump rate (when stream flow allows) the firm yield of the Adrian reservoir system is estimated to be 0.492 mgd.

Demand on the Adrian reservoir in 2008 is approximately 0.588 mgd, which exceeds the calculated firm yield of 0.492 mgd derived from the RESOP model. Although current (2008) demand exceeds the calculated firm yield, it should be noted that the firm yield value was based on a maximum pump rate of 500 gallons per minute at the intake location on the South Grand River. A larger capacity pump or multiple pumps working in tandem would increase the calculated firm yield from the reservoir system to accommodate for the additional demand.

III. RESOP Model Parameters

Terms in brackets refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Adrian Reservoir (figure 1.1) conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on June 6, 2003. These relationships are illustrated in figure 1.4.a for the primary (lower) lake and (figure 1.4.b) for the sediment control basin.

Adrian Reservoir (Upper and Lower Lakes)

Lower (Primary) Lake			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
832	0.4	0.1	
834	2.9	3.4	
836	7.1	12.7	
838	13.9	33.5	
840	21.5	69.1	
842	29.7	120	
844	42	190	
846	47.7	280	Lake conditions June 6, 2003
846.2	49.8	290	Spillway

Upper Lake (Sediment Control Basin)			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
844	0.1	0.01	
846	0.9	1	
848	2.9	4	
850	5.8	13	
850.7	7.4	17	Lake conditions June 6, 2003
852	12.7	31	
852.3	13.8	35	Spillway

[LIMITS]

Lower (Primary) Lake
Maximum storage ....290 acre-feet
Minimum storage ....40 acre-feet
Drainage basin size .... 352 acres

Upper Lake (Sediment Control Basin)
Maximum storage ....35 acre-feet
Minimum storage ....0 acre-feet
Drainage basin size .... 166.4 acres

Combined drainage basin size .... 518.4 acres

Initial storage volume was equated to the reservoir volume at maximum capacity for both lakes.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]
Seepage from the primary lake was estimated to be 2.0 inches per month when the reservoir is at or near full capacity and 0.0 inches per month as the water level approaches the lower limits

of the pool. The earthen dam on the Adrian Reservoir is composed primarily of clay-rich materials and seepage through the dam is minimal.

Seepage for the sediment control basin is minimal and assumed to drain directly into the primary lake. A seepage rate of 0.2 inches per month was used for the upper lake when the lake is at maximum capacity and 0.0 inches when near empty.

[RAINFALL]

Precipitation rates from Butler, Missouri (approximately 8 miles south of Adrian) were used for this analysis and supplemented with data from Appleton City, Missouri. Average annual precipitation in Butler from 1970 through 2000 was 42.05 inches. Annual precipitation in Butler from 1953 through 1957 was 28.8 inches, 35.7 inches, 28.4 inches, 21.3 inches, and 37.5 inches, respectively.

[RUNOFF]

Regional monthly runoff values were determined from stream gauge data. A monthly runoff volume in watershed inches was determined from data collected at the Little Blue River gauge near Lake City, Missouri. Another gauge on Cedar Creek (near Pleasant View, Missouri) was also comparatively analyzed. Measurements recorded at the lake were similar to those observed at the two gauges. Regional runoff was determined from the Little Blue River drainage basin, which has soil types and topography similar to that of Adrian. Some regions of the Little Blue River drainage basin are urbanized; however, the additional monthly runoff volume expected from these regions did not significantly affect the results. For months where precipitation values appeared inconsistent with measured runoff values, daily rainfall values were considered. Antecedent moisture was estimated for each rainfall event and adjustments to the Natural Resource Conservation Service (NRCS) runoff curve number were made to estimate runoff for each storm event.

[EVAP]

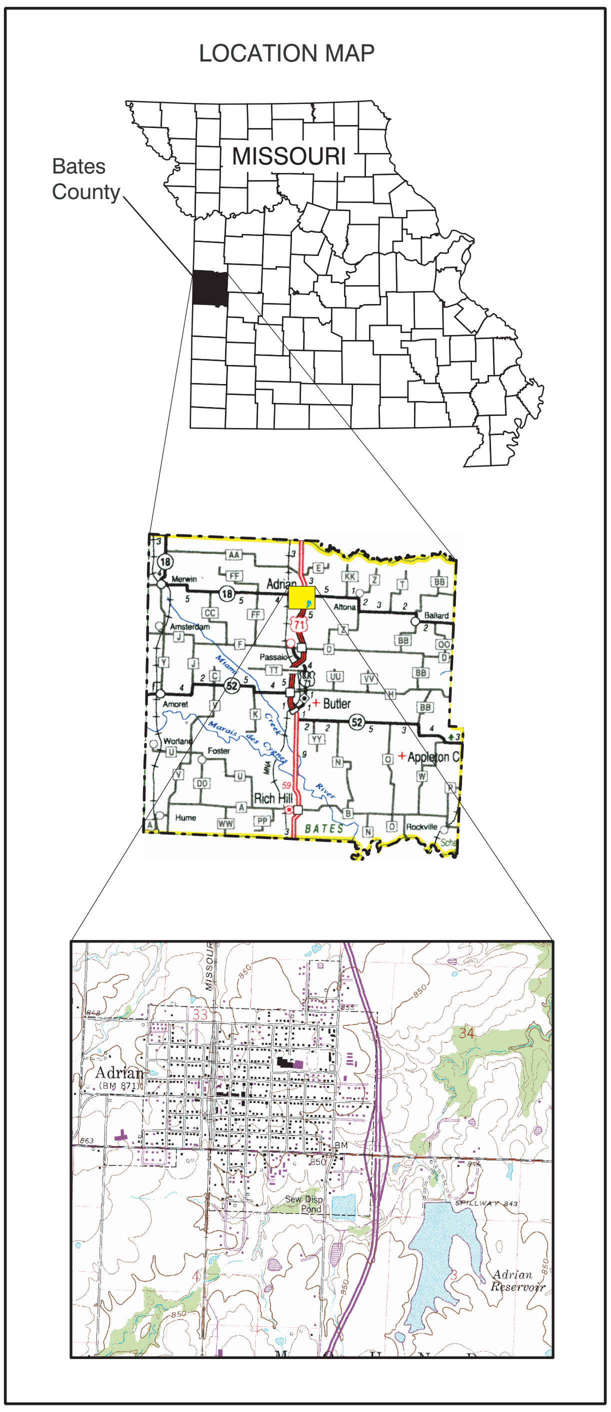
Pan evaporation values from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from the reservoir due to evaporation. An adjustment factor of 0.76 was applied to derive this parameter.

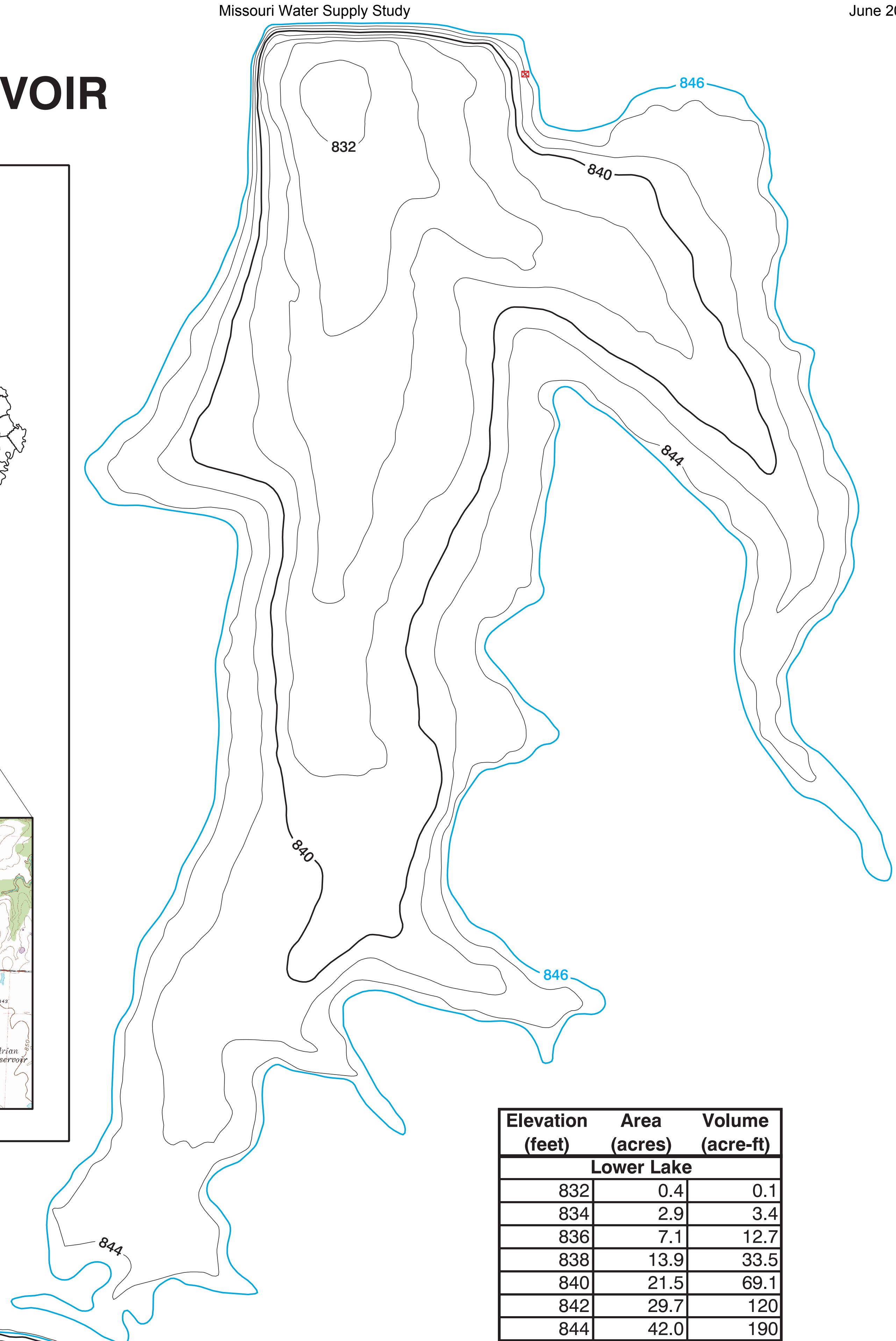
[DEMAND]

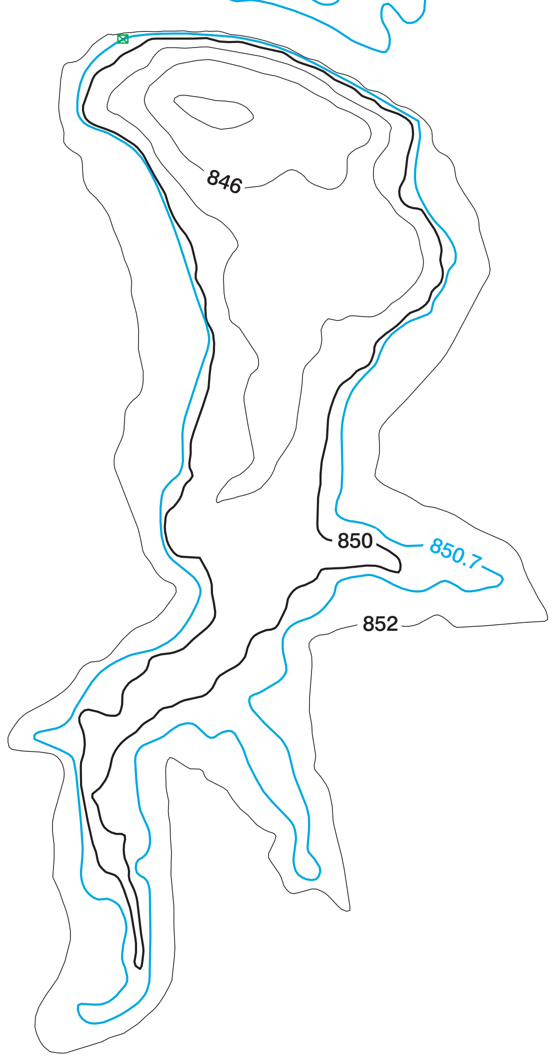
For this analysis 0.737 mgd was used for evaluation.

Values for water usage by Adrian are illustrated in figure 1.2. Between 1992 and 2003, water demand in Adrian was fairly constant at 0.373 mgd. Optimum demand (yield) from Adrian Reservoir without an additional source of water (diverting from the South Grand River) is 49,500 gallons per day.

ADRIAN RESERVOIR







Elevation (feet)	Area (acres)	Volume (acre-ft)
Lower Lake		
832	0.4	0.1
834	2.9	3.4
836	7.1	12.7
838	13.9	33.5
840	21.5	69.1
842	29.7	120
844	42.0	190
846	47.7	280
846.2	49.8	290
Upper Lake		
844	0.1	0.01
846	0.9	1
848	2.9	4
850	5.8	13
850.7	7.4	17
852	12.7	31
852.3	13.8	35

Lake elevations and respective surface areas and volumes. Lower lake spillway elevation 846.2 feet. Upper lake spillway elevation 852.3 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).

EXPLANATION

— 840 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

— 846 — WATER SURFACE—Shows approximate elevation of water surface, June 5-6, 2003 (table 27). Actual elevation of lower lake 846.1 Actual elevation of upper lake 850.7.

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on south side top of concrete block surrounded by water at full pool. Elevation 847.1 feet.

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on top of 18 inch culvert. Elevation 852.7 feet.

0 300 600 FEET
0 100 200 METERS

USGS
science for a changing world

Bathymetric map and area/volume table for Adrian Reservoir near Adrian, Missouri.

In cooperation with Missouri Department of Natural Resources

Figure 1.1

Adrian Lake
Water Supply Study - Adrian, Missouri
Water Use

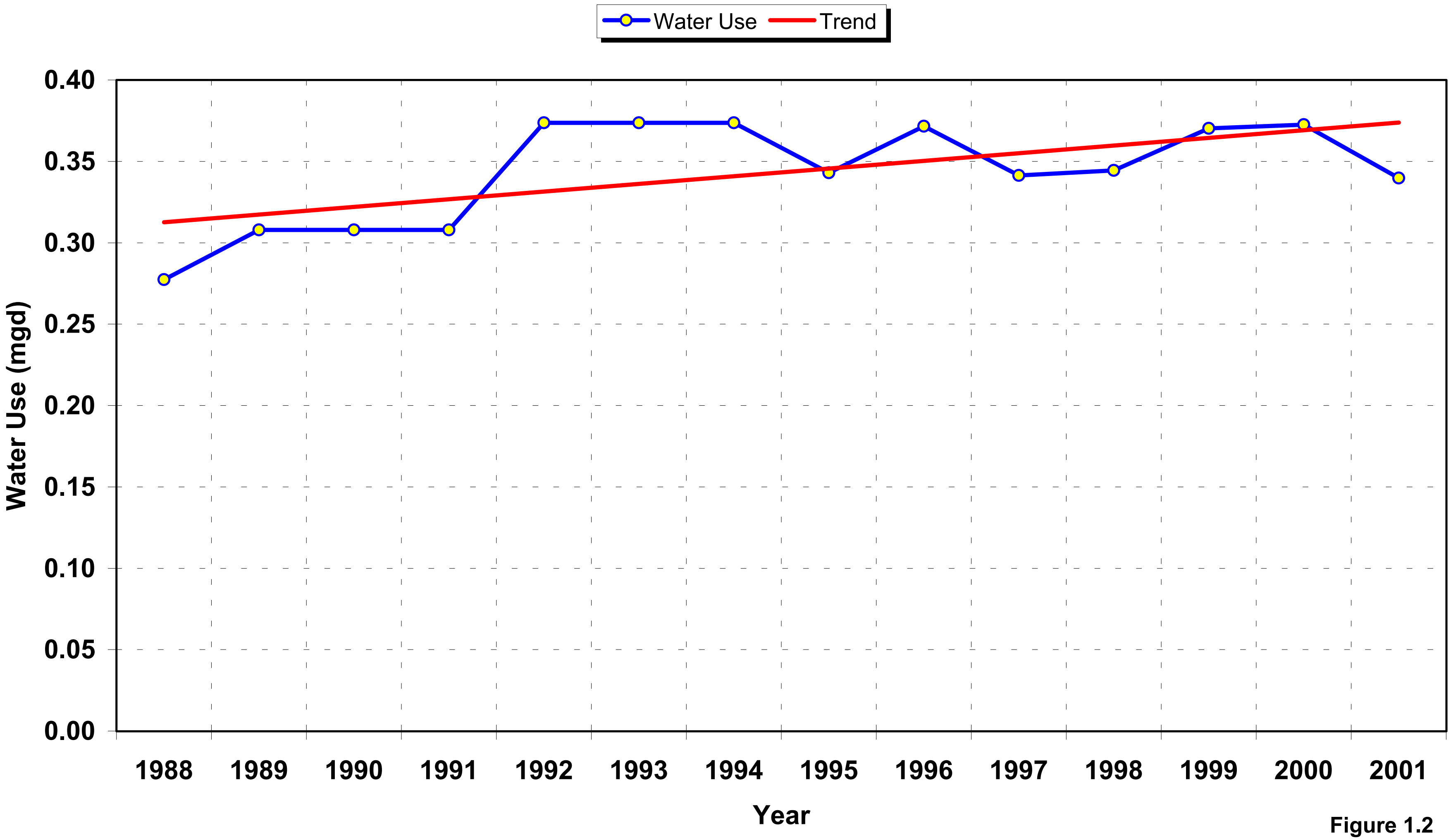


Figure 1.2

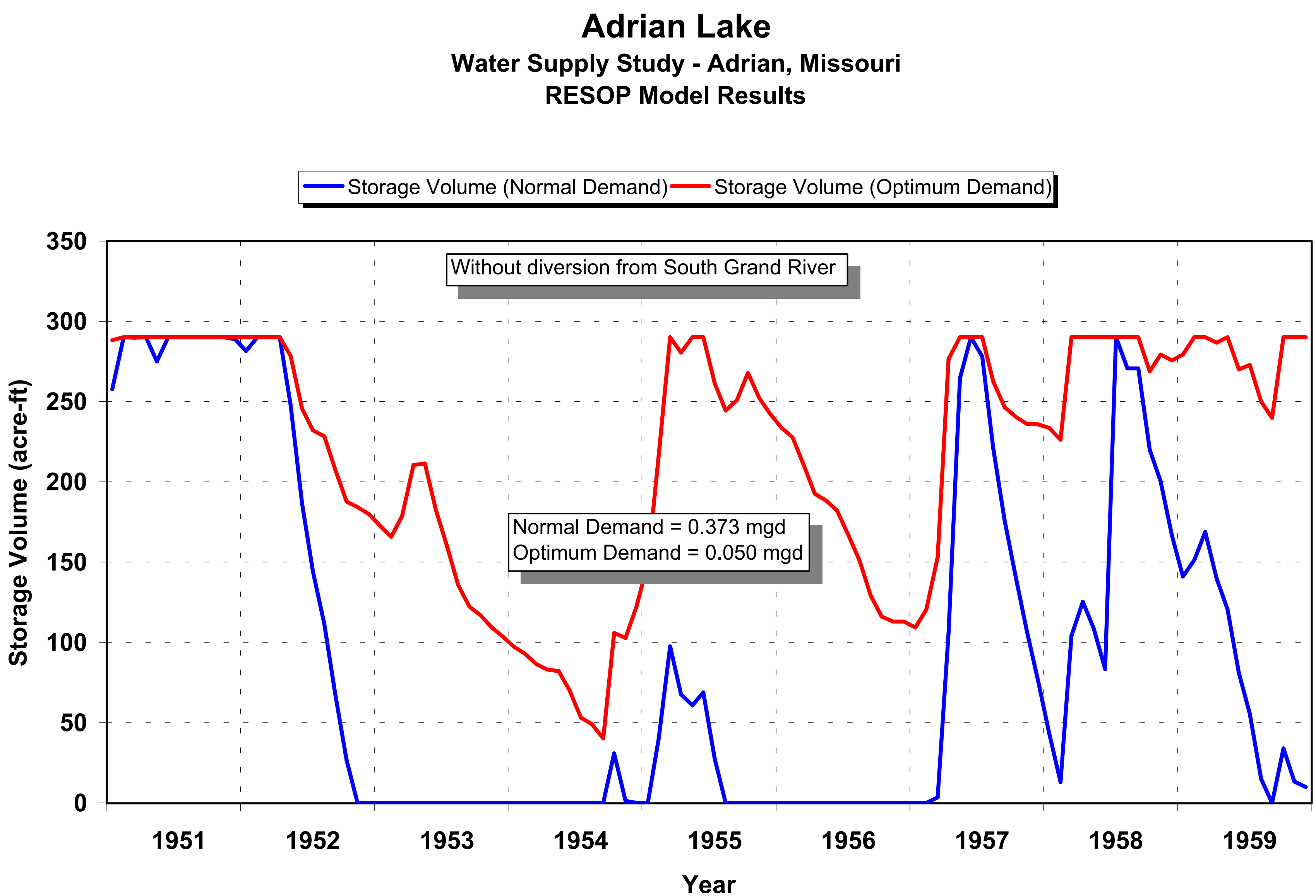

Adrian Lake
Water Supply Study - Adrian, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Without diversion from South Grand River
Normal Demand = 0.373 mgd
Optimum Demand = 0.050 mgd
Storage Volume (acre-ft)
0
50
100
150
200
250
300
350
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 1.3.a

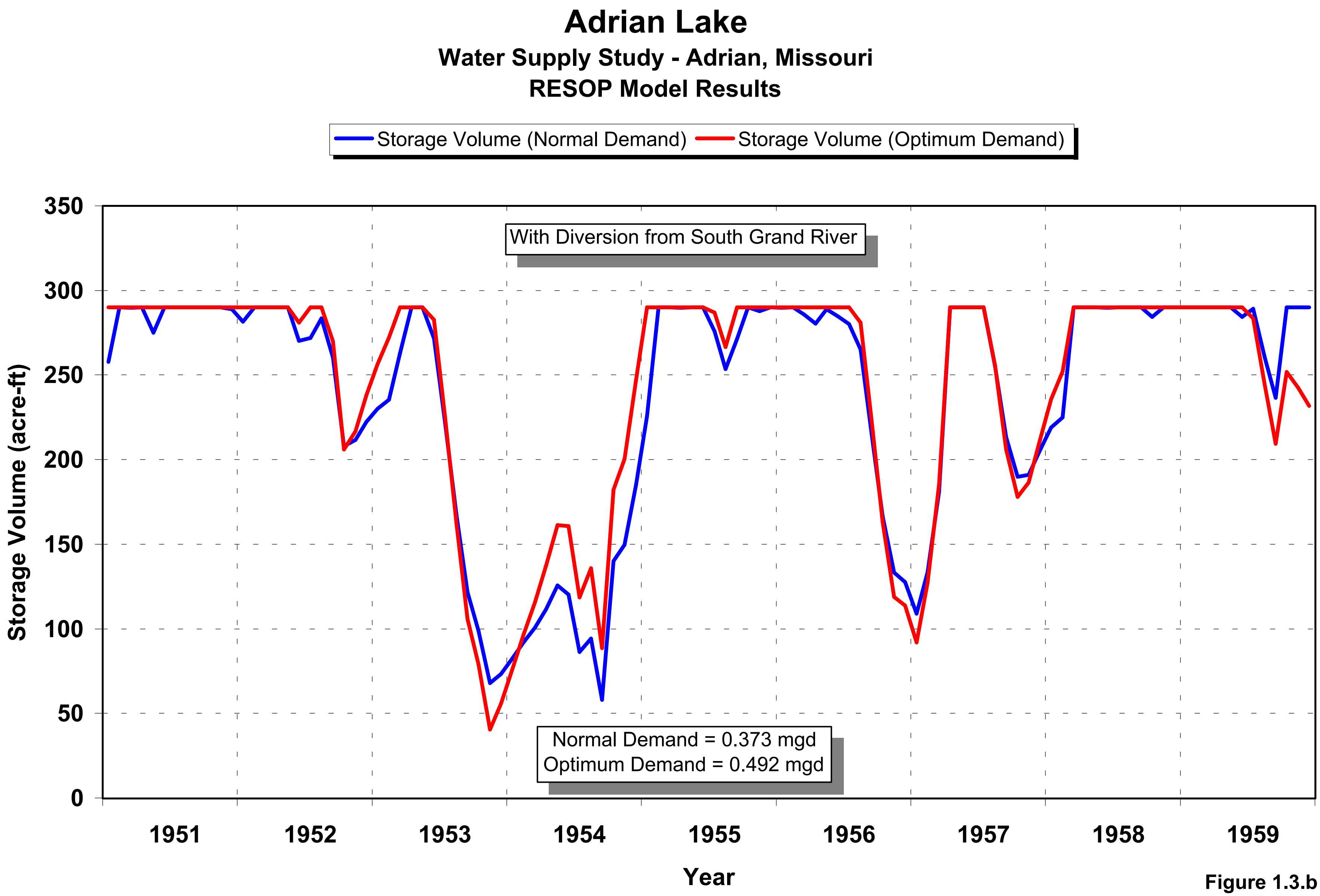

Adrian Lake
Water Supply Study - Adrian, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
With Diversion from South Grand River
Normal Demand = 0.373 mgd
Optimum Demand = 0.492 mgd
Storage Volume (acre-ft)
350
300
250
200
150
100
50
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 1.3.b

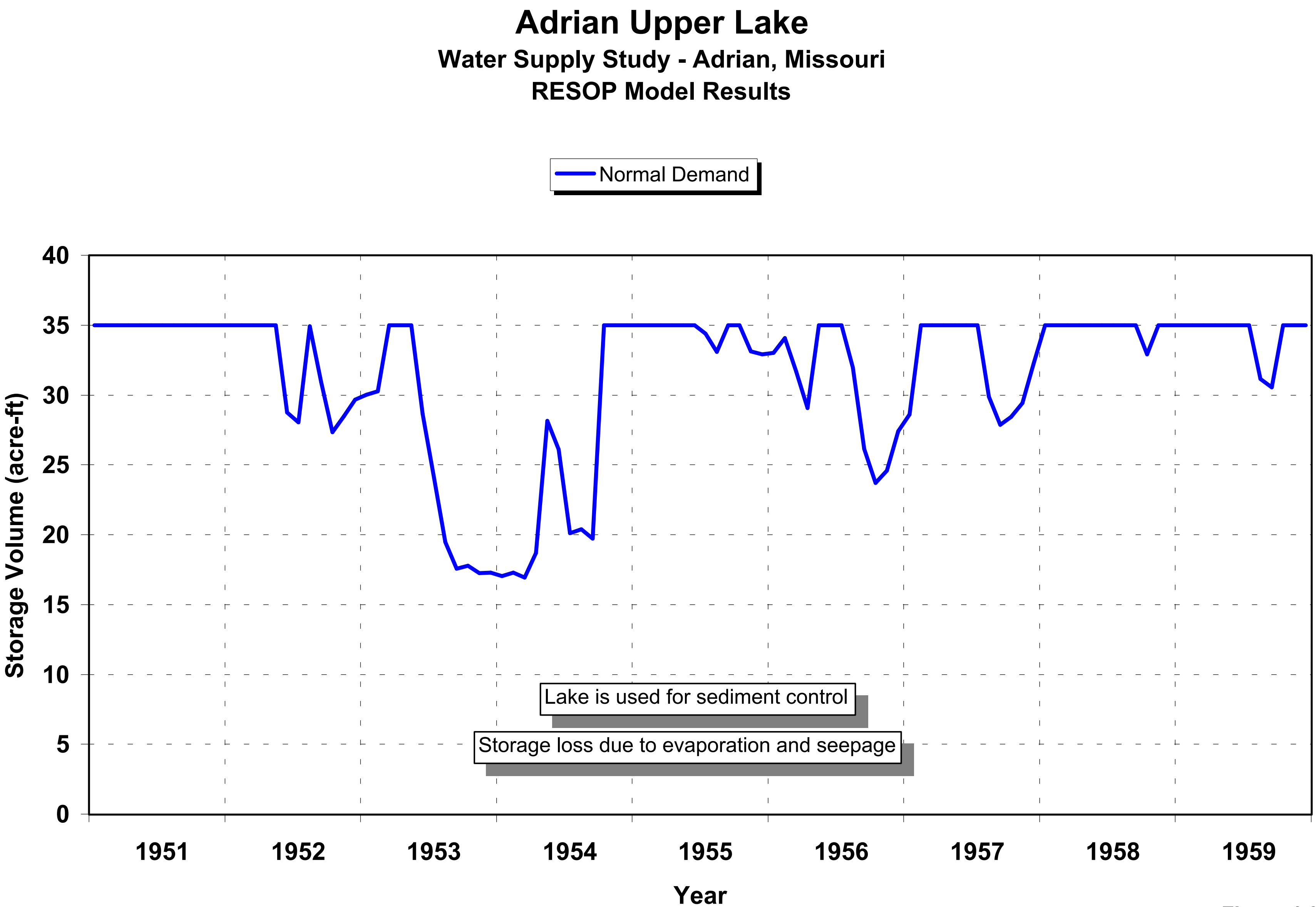

Adrian Upper Lake
Water Supply Study - Adrian, Missouri
RESOP Model Results
Normal Demand
40
35
30
25
20
15
10
5
0
Storage Volume (acre-ft)
Lake is used for sediment control
Storage loss due to evaporation and seepage
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 1.3.c

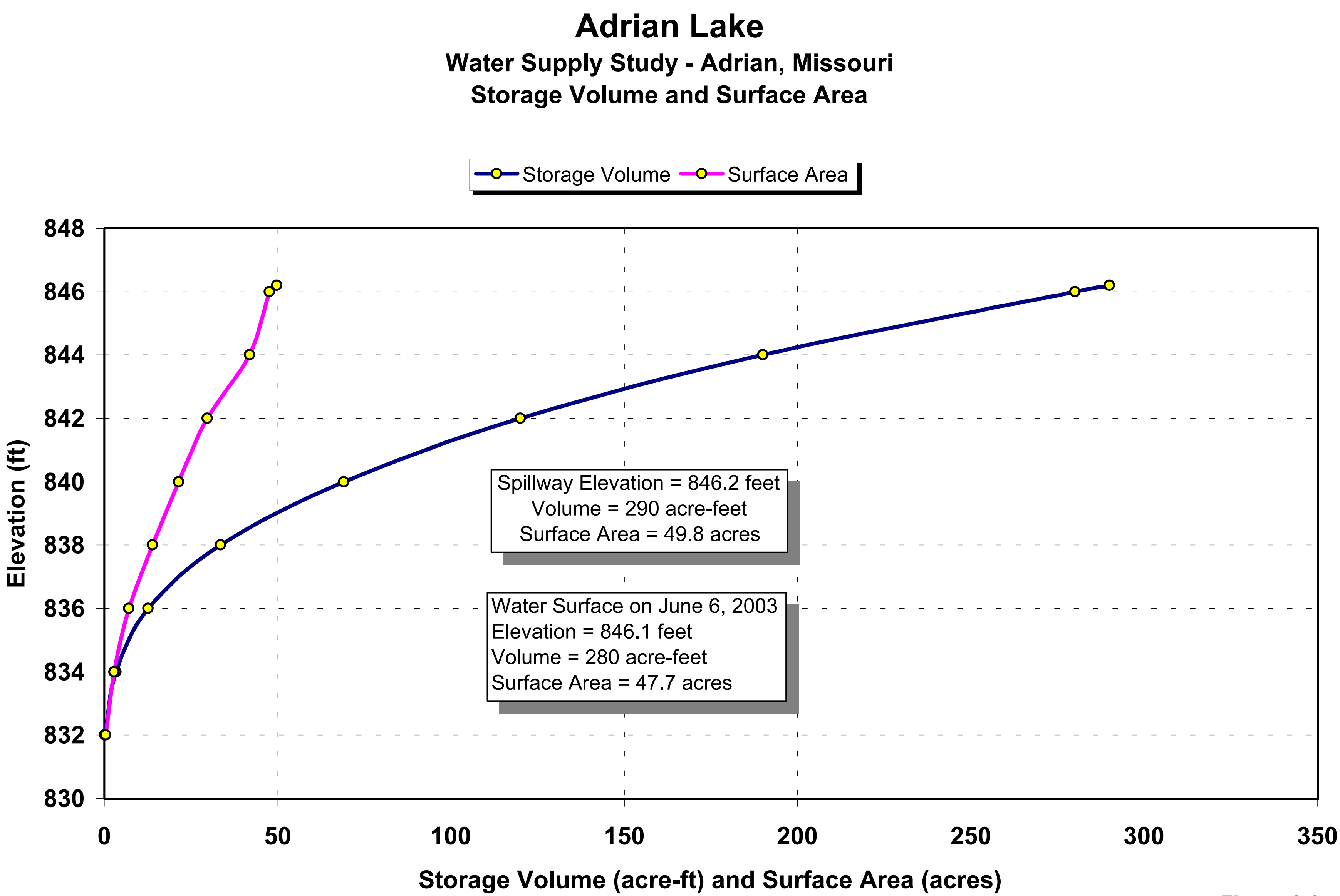

Adrian Lake
Water Supply Study - Adrian, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
848
846
844
842
840
838
836
834
832
830
Elevation (ft)
0
50
100
150
200
250
300
350
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 846.2 feet
Volume = 290 acre-feet
Surface Area = 49.8 acres
Water Surface on June 6, 2003
Elevation = 846.1 feet
Volume = 280 acre-feet
Surface Area = 47.7 acres

Figure 1.4.a

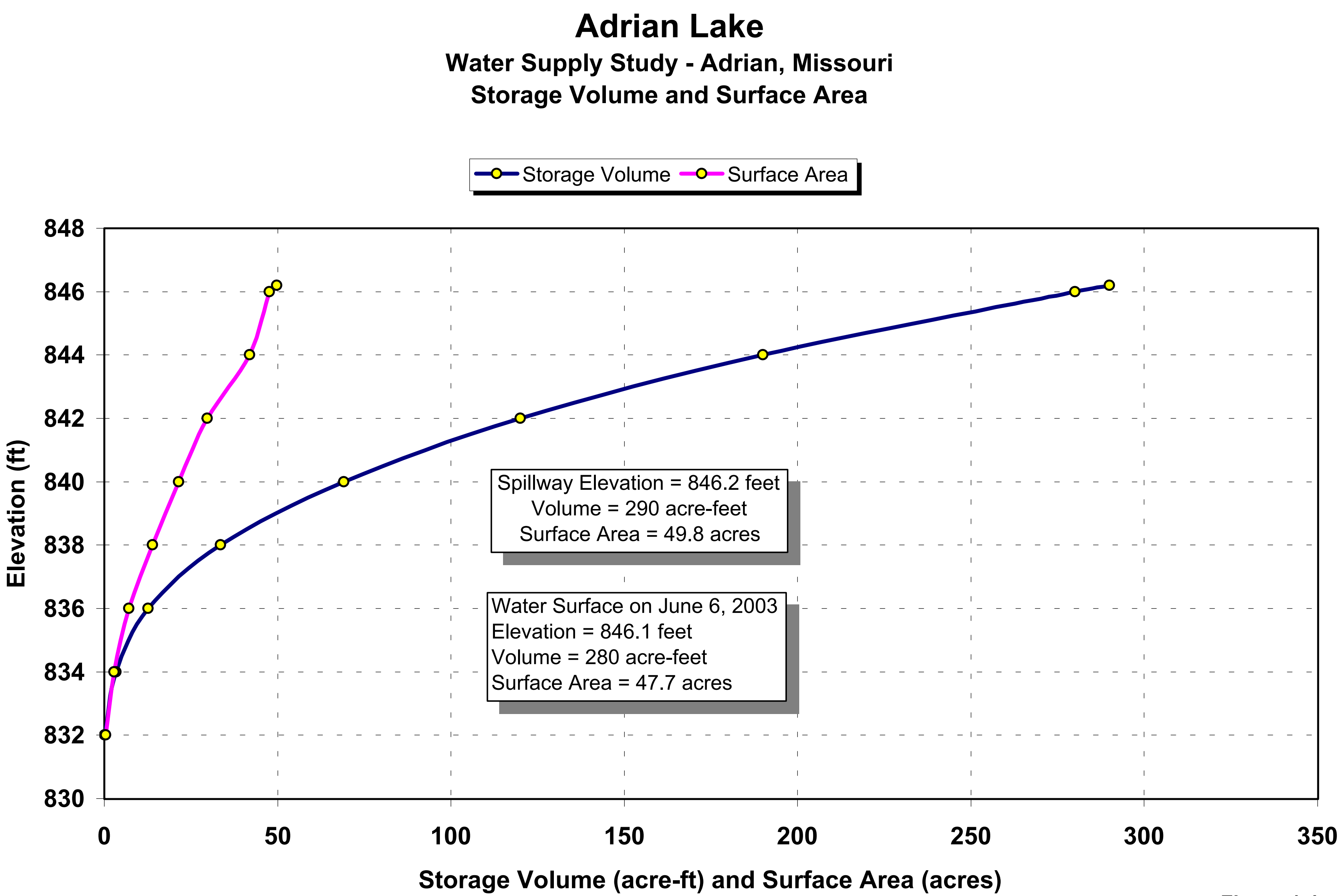

Adrian Lake
Water Supply Study - Adrian, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
848
846
844
842
840
838
836
834
832
830
Elevation (ft)
0
50
100
150
200
250
300
350
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 846.2 feet
Volume = 290 acre-feet
Surface Area = 49.8 acres
Water Surface on June 6, 2003
Elevation = 846.1 feet
Volume = 280 acre-feet
Surface Area = 47.7 acres

Figure 1.4.a

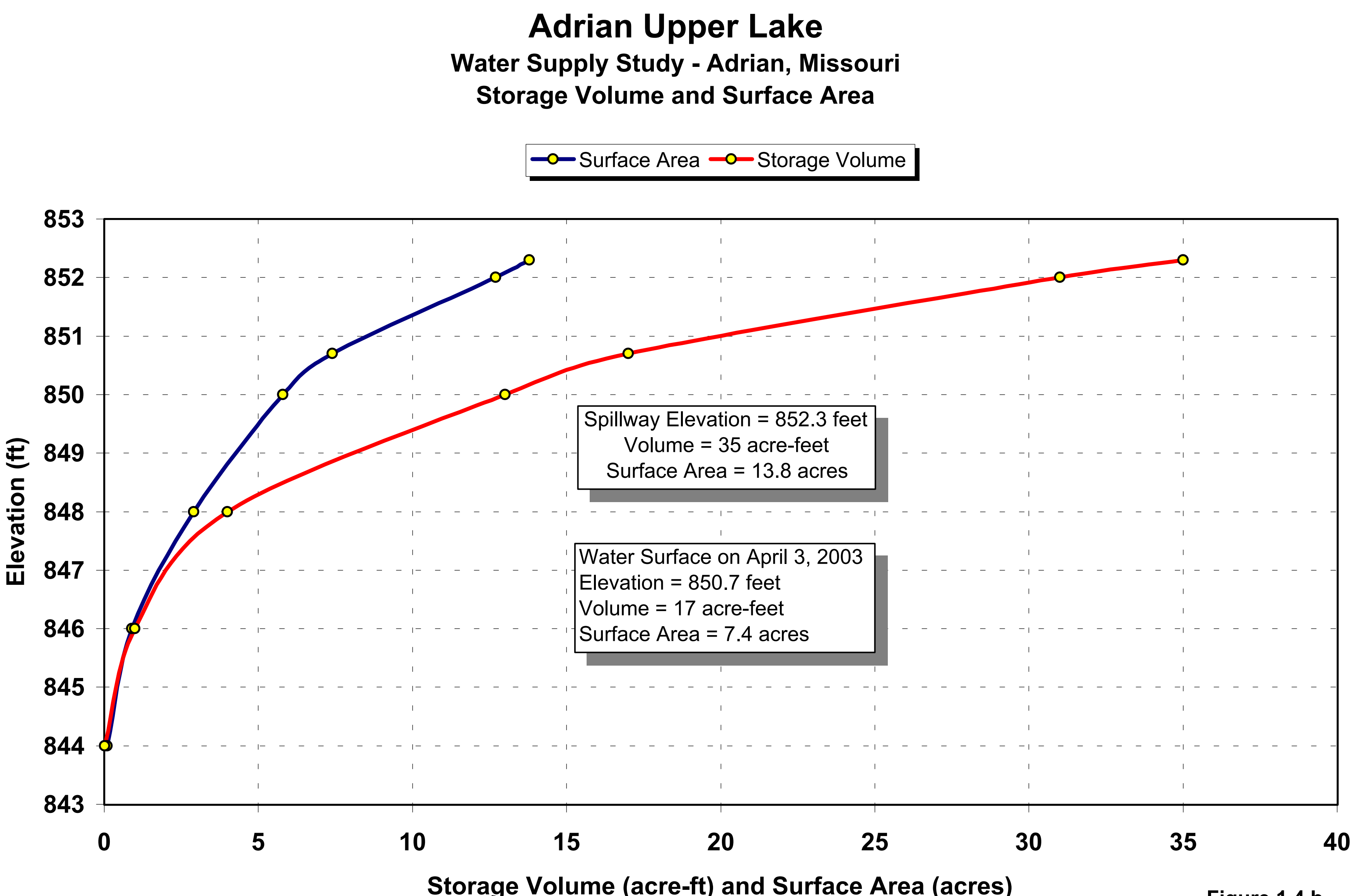

Adrian Upper Lake
Water Supply Study - Adrian, Missouri
Storage Volume and Surface Area
Surface Area
Storage Volume
Elevation (ft)
853
852
851
850
849
848
847
846
845
844
843
0
5
10
15
20
25
30
35
40
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 852.3 feet
Volume = 35 acre-feet
Surface Area = 13.8 acres
Water Surface on April 3, 2003
Elevation = 850.7 feet
Volume = 17 acre-feet
Surface Area = 7.4 acres

Figure 1.4.b

Harrison County Lake C-1
Water Supply Study – Bethany, Missouri
Drought Assessment Analysis

I. Overview

Harrison County Lake (West Fork of Big Creek C-1), located in central Harrison County, (figure 2.1) is designed for flood control, recreation and municipal water supply. The lake was planned as a flood prevention and water supply lake through the USDA's NRCS small watershed program (PL-566), and is about 10 miles North of Bethany. Construction of the lake was begun in 1994 for a two-year construction period. Water supply from Harrison County Lake began in 1999. The reservoir was designed to have 1,095 acre-feet of storage for domestic use, Bethany sponsored 679 acre-feet and Harrison County Commission, along with Harrison County PWSD #2 sponsored 416 acre-feet and an additional 711 acre-feet is allocated for recreation. . The Bethany and Harrison County Reservoir system serves a population of approximately 3,160 with an estimated water demand of 0.35 million gallons per day for Bethany according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). Missouri Department of Conservation manages Harrison County Lake for fish and wildlife.

Harrison County Lake is located in Section 30, Township 65 North, Range 28 West and was surveyed by NRCS as part of the "West Fork of Big Creek" watershed plan development. Municipal and industrial water supply was planned and included to supplement Bethany's water supply and to provide for domestic water for rural water supply districts, they currently are Harrison County Public Water Supply District #2, Cainsville, Coffee, Davies County PWSD #2, Gilman City and Ridgeway. The design provides for release to in-stream flow needs for water quality concerns of 0.35 cubic feet per second (cfs).

The two Bethany lakes, reported as Bethany New Lake and Bethany Old Lake, are the primary source of water for Bethany. These two lakes were not surveyed, as a result it was necessary to estimate the surface area and storage volume in order to estimate optimum yields. To do that the elevations and corresponding surface area were determined from a 7.5 minute USGS topographic map. The area below the spillway elevation was assumed to be a ratio of the Harrison County Reservoir. Volume was then determined based on that area. Figure 2.4.b and 2.4.c illustrate the results. Figure 2.4.a represents Harrison County Lake.

A consulting engineering firm, George Butler, Inc., was hired to establish the volume of domestic water needs to meet demand and make projections for water use. The drought of record was during the 1950's. This study evaluated the effects that drought would have on the availability of water supplies. Figure 2.2 illustrates Bethany's water demand. Bethany treatment plant receives water from Bethany Old Reservoir. Water is transferred from Harrison County Reservoir to Bethany New Reservoir and then transferred from Bethany New Reservoir to Bethany Old Reservoir.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Two scenarios were modeled for Harrison County Reservoir. The model assumes that ‘Normal’ demand for Harrison County Reservoir to be 0.22 million gallons per day and that ‘Optimum’ demand from the lake’s domestic water supply is 0.59 million gallons per day. ‘Optimum’ demand was performed to determine the firm yield that represents the viable quantity of water available.

An additional test allowed the water allocated to recreation to be used in addition to the domestic water supply resulting in an optimum yield of 1.32 million gallons per day. Figure 2.3.a illustrates these relationships. Figures 2.3.a and 2.3.b show optimum demand for Old and New Lakes.

II. Drought Assessment Summary

Harrison County Reservoir along with Bethany Old Reservoir and Bethany New Reservoir meets Bethany’s 2002 demand of 0.365 million gallons per day. Harrison County Reservoir’s share of this demand was estimated to be 0.22 million gallons per day. The volume allocated to domestic uses is 1095 acre-feet. RESOP analysis results in 358 acre-feet remaining in the pool. Optimum demand would be 0.59 million gallons per day. Another test allowed the recreation storage be used. This resulted in a demand of 1.32 million gallons per day.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Harrison County Lake (West Fork of Big Creek Watershed, Lake C-1) conducted by the United States Department of Agriculture, Natural Resources Conservation Service (NRCS). Surface area of the lake and associated storage volume capacities are illustrated in figure 2.4.

Storage allocation:
Sediment…………………………………………….= 1,036 acre-feet
Municipal Water Supply for Bethany..……………= 679 acre-feet.
Ag. Water for Rural Water Supplies…...………..= 416 acre-feet.
Recreation………………………………………...= 711 acre-feet
Floodwater Retarding………………………………= 3,592 acre-feet.
Total at Emergency Spillway...…………………….= 6,434 acre-feet.

Harrison County Reservoir Physical Data

Harrison County Reservoir		
Elevation (feet)	Area (acres)	Volume (acre-feet)
940	23.48	66.3
944	54.38	222.0
948	91.24	513.2
952	143.00	981.7
956	211.95	1,691.6
960	280.23	2,676.0
964	345.03	3,926.5
968	429.60	5,475.8

972	513.87	7,362.7
976	616.64	9,623.7
980	720.88	12,298.8
984	846.17	15,432.8

Principal Spillway Elevation……………………………………….= 960.0 feet.
Emergency Spillway Elevation …………………………….……..= 970.1 feet.
Top of Dam Elevation…..………………………………………….= 975.1 feet

Bethany New Reservoir				***Bethany Old Reservoir***		
Elevation (feet) Assumed	Area (acres) Estimated	Volume (acre-feet)		Elevation (feet) Assumed	Area (acres) Estimated	Volume (acre-feet)
72	0	0		76	0	0
76	1	2		80	1	3
80	4	12		84	3	13
84	10	39		88	6	30
88	16	91		92	9	59
92	26	175		96	13	102
96	38	302		100	17	162
100	50	499				

Assumed spillway elevation for both lakes = 100 feet.
Surface areas estimated based on USGS 7.5-minute topographic maps.

[LIMITS]

<u>Harrison County Lake</u>
Maximum storage……………………………………………………...2,842 acre-feet
Minimum storage for domestic use……………..…………………..1,581 acre-feet
Minimum storage for domestic use and recreation …………………870 acre-feet
Drainage basin size…………………………………………….…..17.2 square miles

Initial storage was equated to the reservoir volume at maximum capacity.

<u>Bethany New Lake</u>
Maximum storage.………………………………………………….….477 acre-feet
Minimum storage……………………….…………………..…………….15 acre-feet
Drainage basin size…..…………………………………………….1.17 square miles

Initial storage was equated to the reservoir volume at maximum capacity.

<u>Bethany Old Lake</u>
Maximum storage…...………………………………………….……….162 acre-feet
Minimum storage……………...…………………………………………10 acre-feet
Drainage basin size…………………………………………….....0.34 square miles

Initial storage was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought is in the 1950's. The analysis used in this model is January 1951 and ended December 1959.

[SEEPAGE]

Seepage from Harrison County Lake estimated to be 0.5 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.
Bethany Old Reservoir was estimated to be 0.1 inches per month when full and Bethany New Reservoir was estimated to be 0.25 inch per month. Both reservoirs' seepage is near 0.0 as the water level is drawn down.

[RAINFALL]

Precipitation values for the drought of record were obtained from the Bethany, Missouri rain gauge.

Average precipitation in Bethany was 37.24 inches between 1970 and 2000. Precipitation values for the drought of record were obtained from Bethany, Missouri (approximately 8-miles south of Ridgeway). The most severe drought occurred between 1953 and 1957 with annual precipitation values in Bethany of 24.09 inches, 32.05 inches, 27.00 inches, 24.31 inches, and 32.27 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the East Fork Big Creek stream gauge, located at Bethany, Missouri. The drainage area monitored by this stream gauge covers approximately 95 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Bethany, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Harrison County Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to derive this value.

[DEMAND]

Normal demand from Harrison County Lake for this analysis is 0.22 million gallons per day occurring in 2002.

The demand of 0.22 million gallons per day was arrived at with the following analysis.
Bethany Demand…………………………………………………= .0.365 million gallons per day.
Bethany New Lake Optimum demand = 0.175 million gallons per day.
Bethany Old Lake Optimum demand = 0.051 million gallons per day.
Subtracting to get normal demand from Harrison County Lake = 0.139 million gallons per day.
Add 0.08 million gallons per day for uncertainty….. …………….= 0.220 million gallons per day.

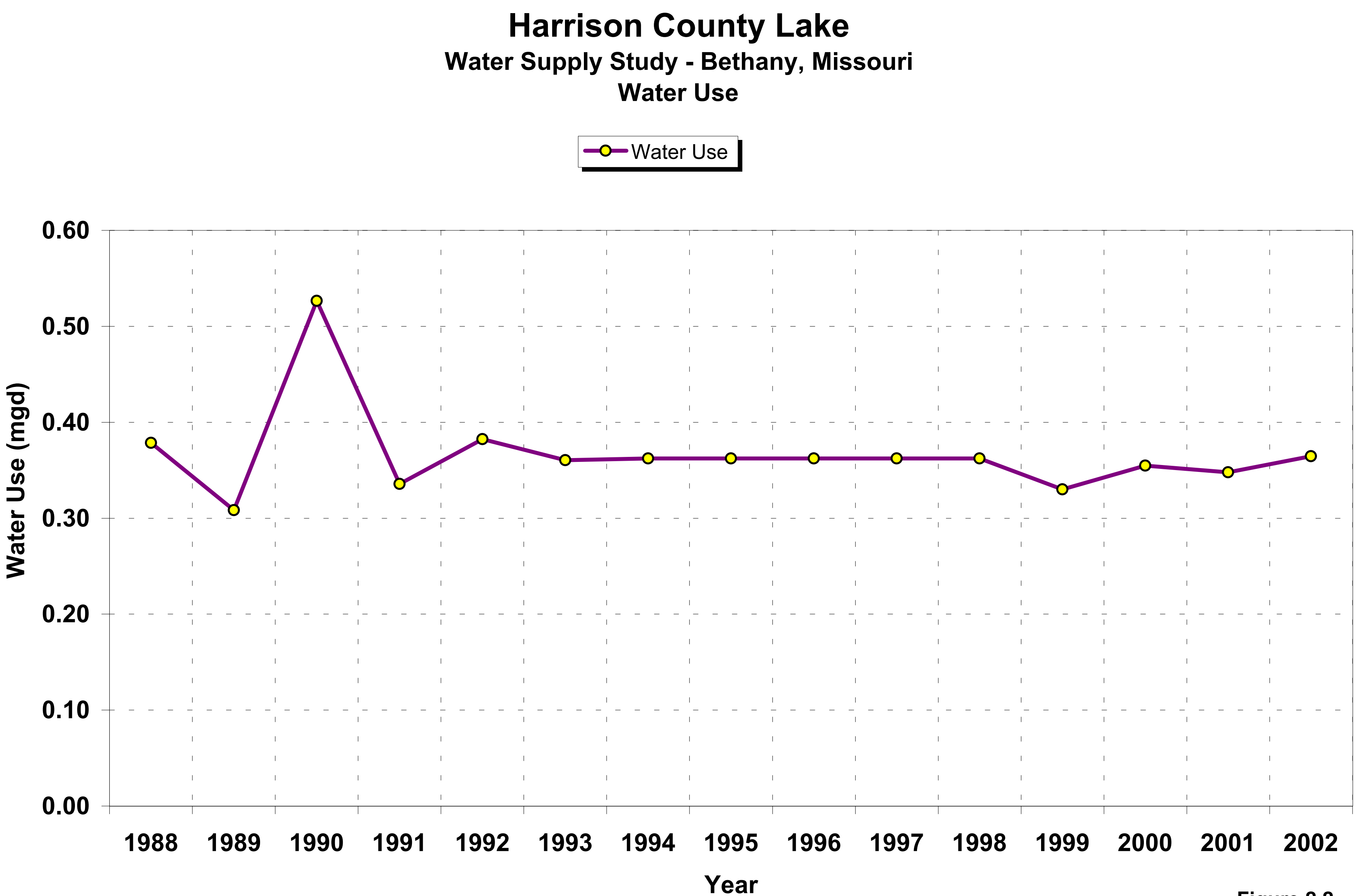

Harrison County Lake
Water Supply Study - Bethany, Missouri
Water Use
Water Use
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Water Use (mgd)
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Year

Figure 2.2

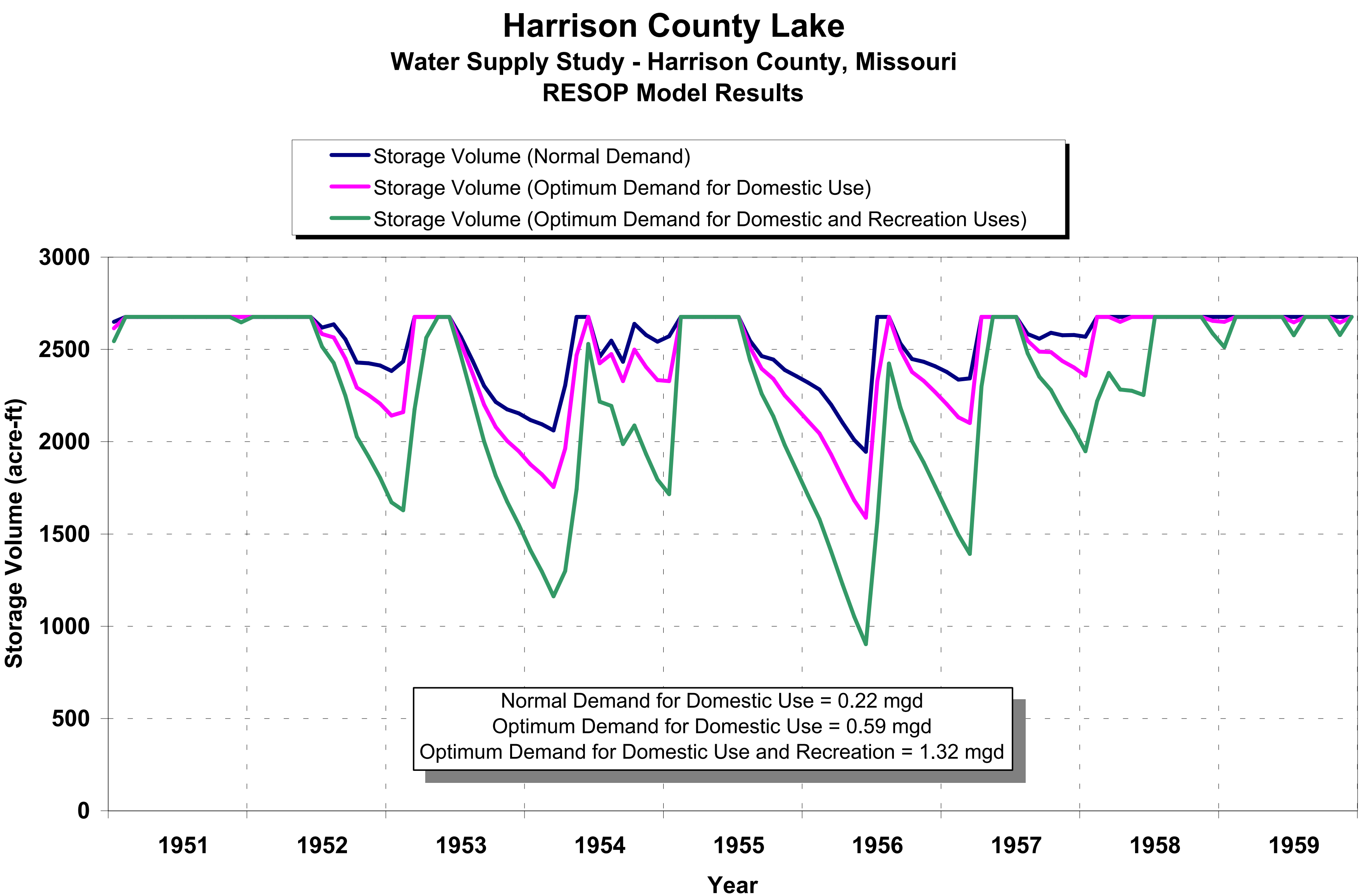

Harrison County Lake
Water Supply Study - Harrison County, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand for Domestic Use)
Storage Volume (Optimum Demand for Domestic and Recreation Uses)
Storage Volume (acre-ft)
3000
2500
2000
1500
1000
500
0
Normal Demand for Domestic Use = 0.22 mgd
Optimum Demand for Domestic Use = 0.59 mgd
Optimum Demand for Domestic Use and Recreation = 1.32 mgd
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 2.3.a

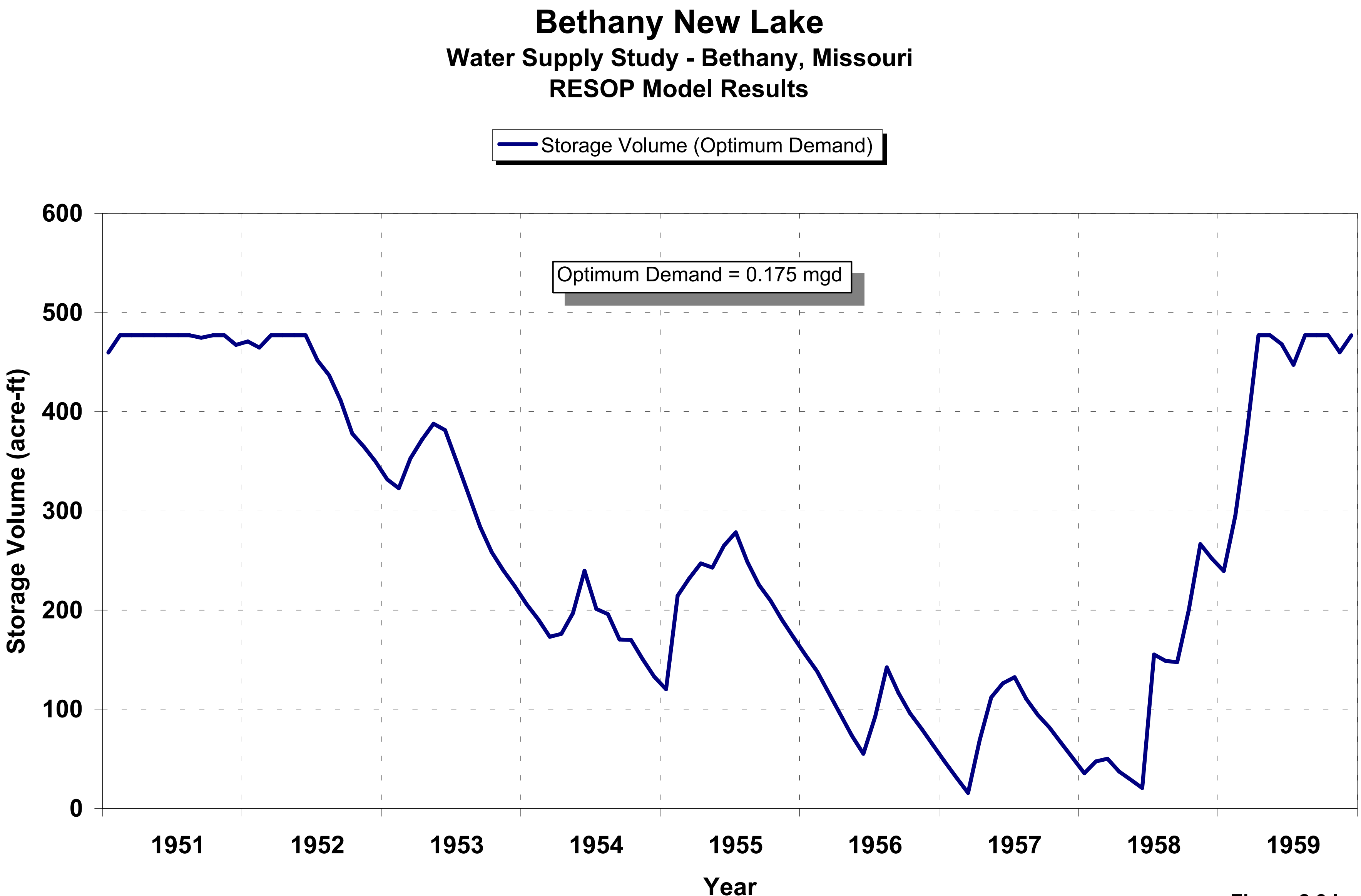

Bethany New Lake
Water Supply Study - Bethany, Missouri
RESOP Model Results
Storage Volume (Optimum Demand)
Optimum Demand = 0.175 mgd
600
500
400
300
200
100
0
Storage Volume (acre-ft)
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 2.3.b

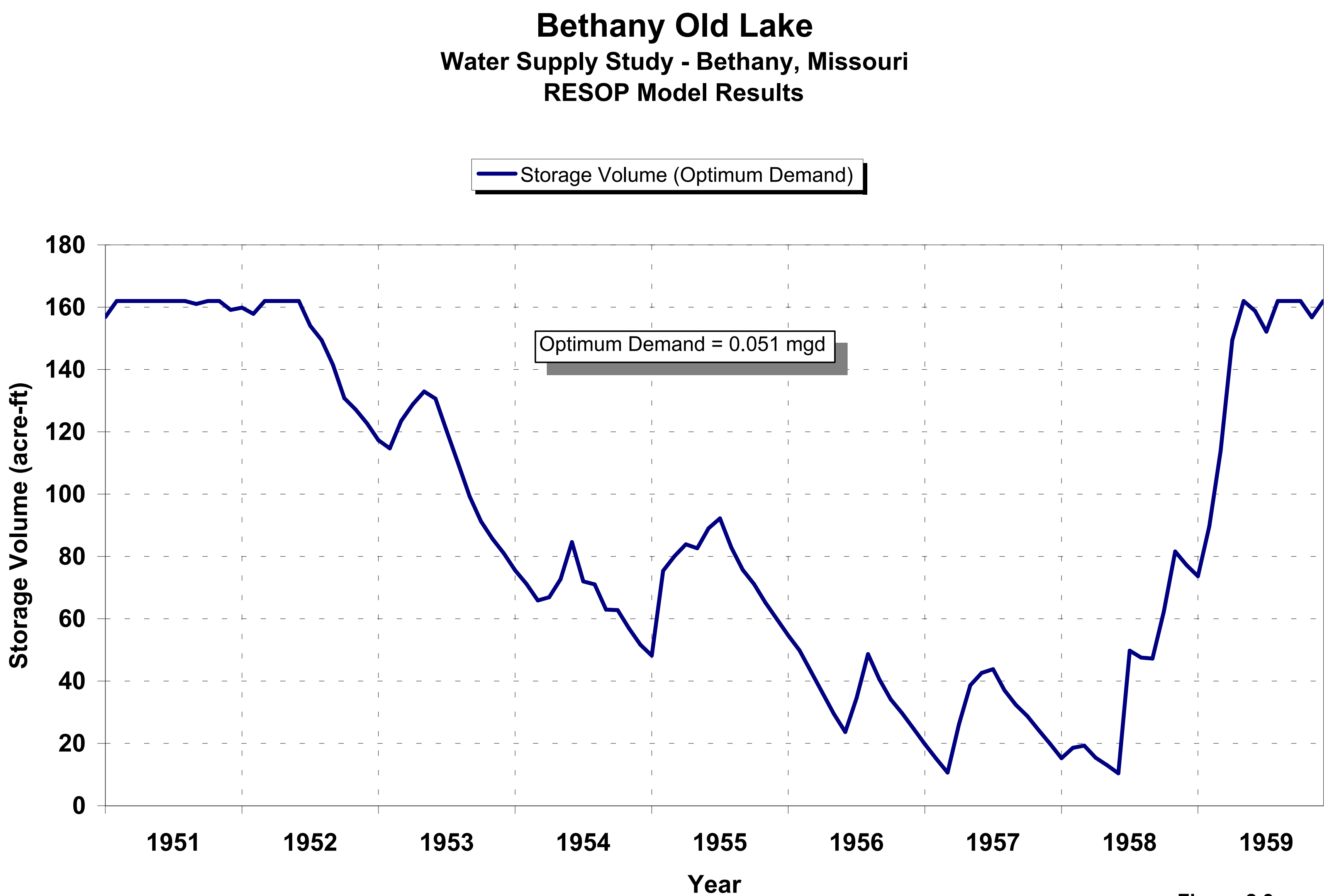

Bethany Old Lake
Water Supply Study - Bethany, Missouri
RESOP Model Results
Storage Volume (Optimum Demand)
Optimum Demand = 0.051 mgd
Storage Volume (acre-ft)
180
160
140
120
100
80
60
40
20
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 2.3.c

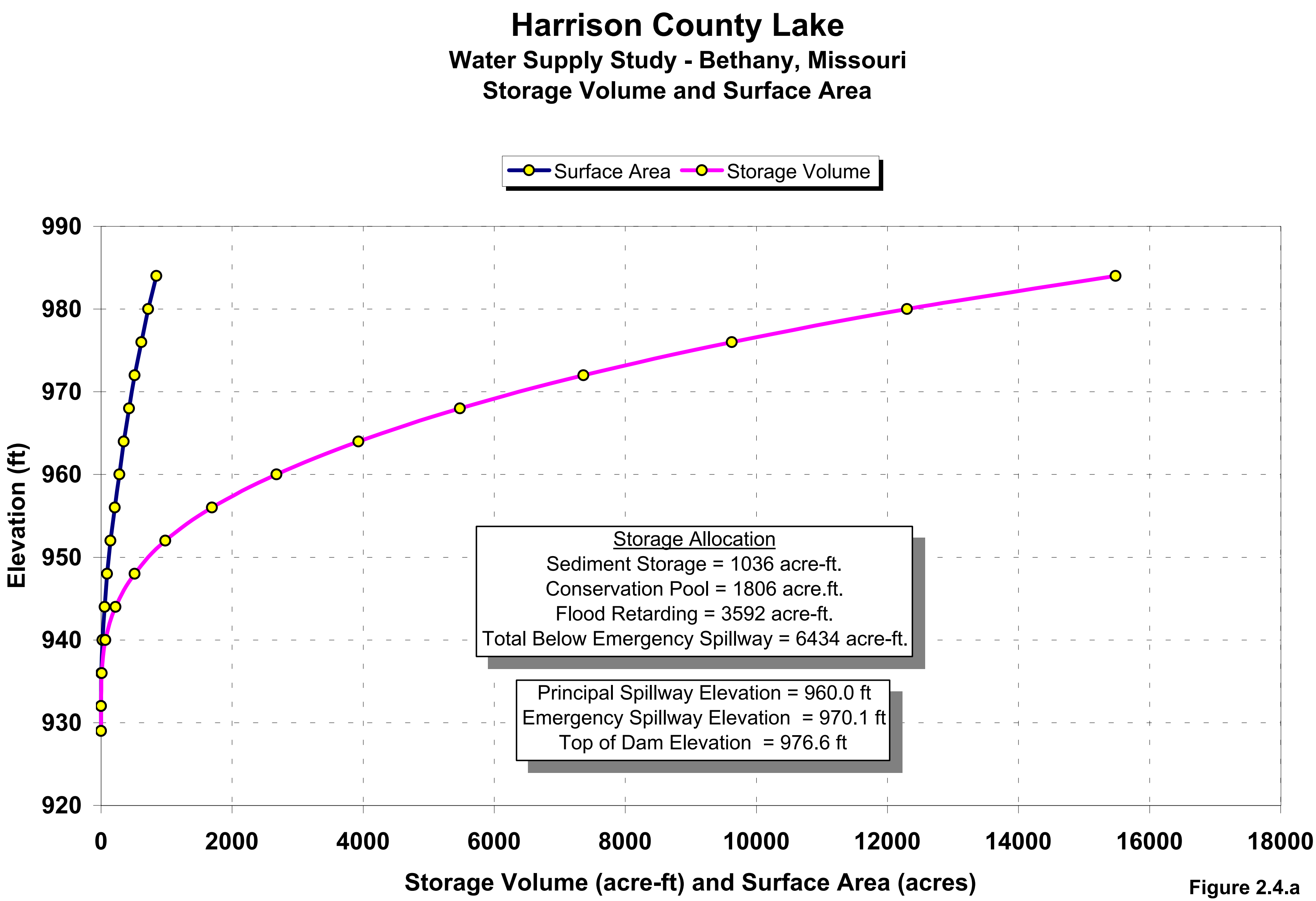

Harrison County Lake
Water Supply Study - Bethany, Missouri
Storage Volume and Surface Area
Surface Area
Storage Volume
990
980
970
960
950
940
930
920
Elevation (ft)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Storage Volume (acre-ft) and Surface Area (acres)
Storage Allocation
Sediment Storage = 1036 acre-ft.
Conservation Pool = 1806 acre.ft.
Flood Retarding = 3592 acre-ft.
Total Below Emergency Spillway = 6434 acre-ft.
Principal Spillway Elevation = 960.0 ft
Emergency Spillway Elevation = 970.1 ft
Top of Dam Elevation = 976.6 ft

Figure 2.4.a

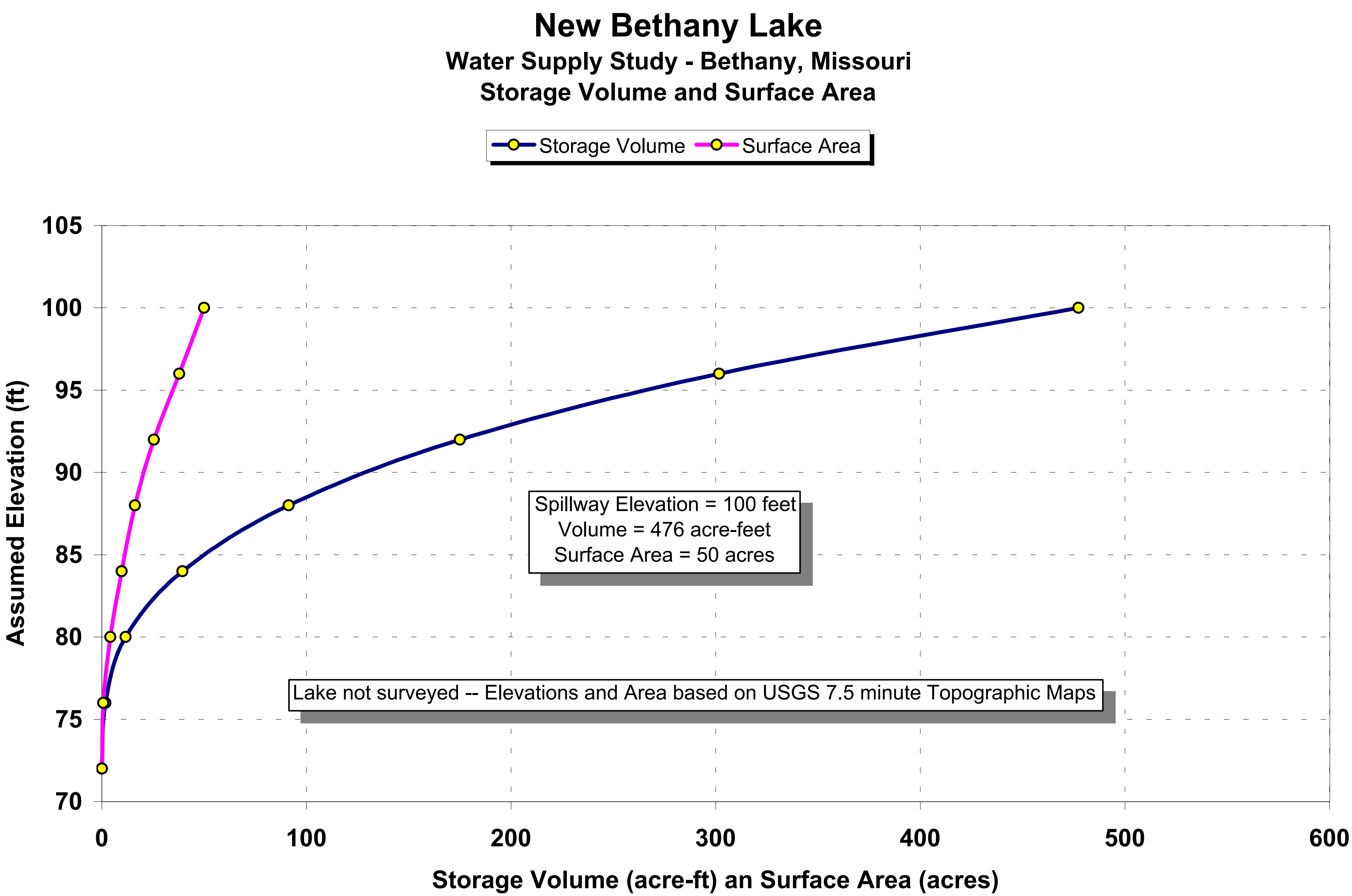

New Bethany Lake
Water Supply Study - Bethany, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
105
100
95
90
85
80
75
70
Assumed Elevation (ft)
0
100
200
300
400
500
600
Storage Volume (acre-ft) an Surface Area (acres)
Spillway Elevation = 100 feet
Volume = 476 acre-feet
Surface Area = 50 acres
Lake not surveyed -- Elevations and Area based on USGS 7.5 minute Topographic Maps

Figure 2.4.b

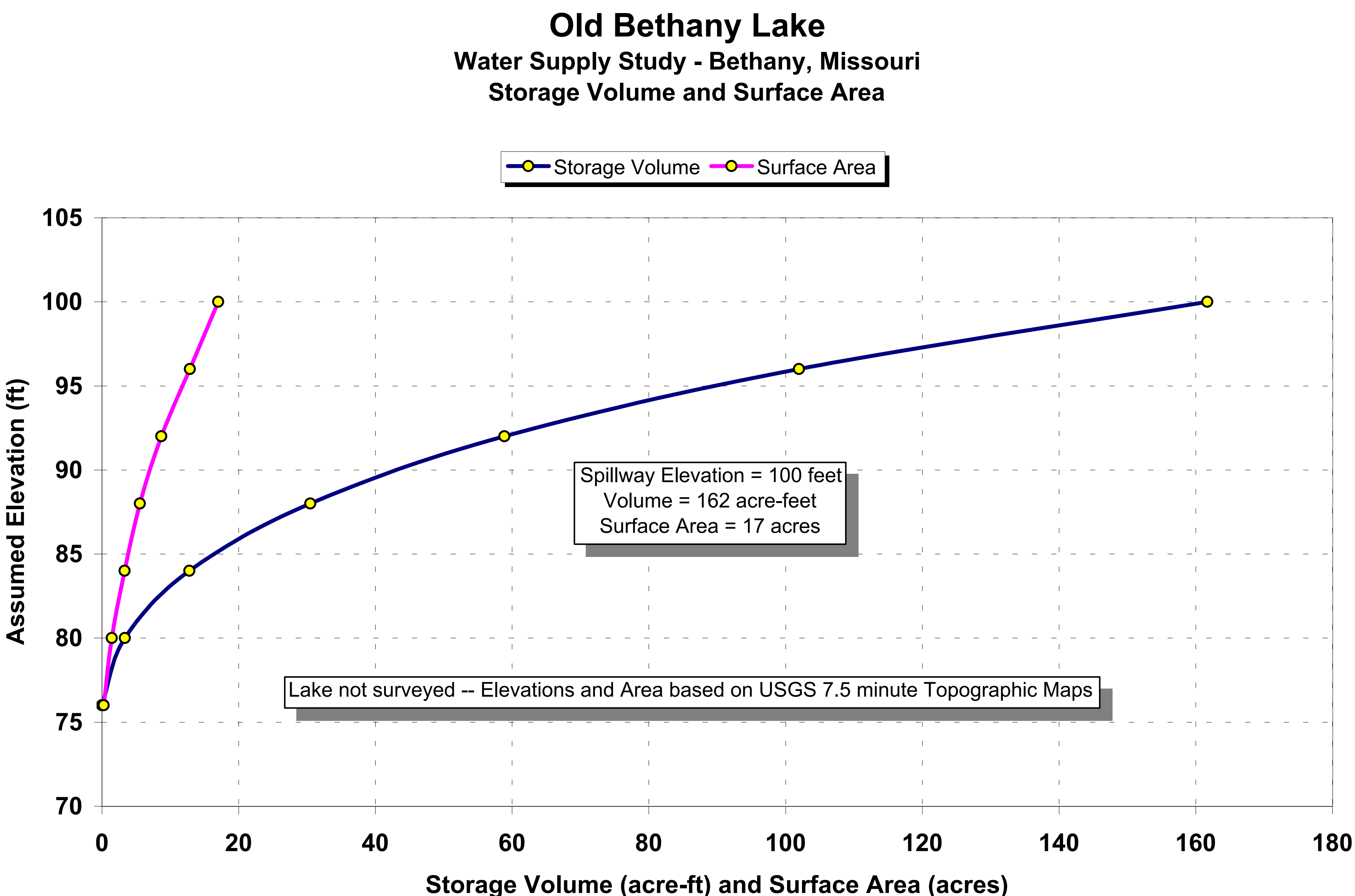

Old Bethany Lake
Water Supply Study - Bethany, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
105
100
95
90
85
80
75
70
Assumed Elevation (ft)
Spillway Elevation = 100 feet
Volume = 162 acre-feet
Surface Area = 17 acres
Lake not surveyed -- Elevations and Area based on USGS 7.5 minute Topographic Maps
0
20
40
60
80
100
120
140
160
180
Storage Volume (acre-ft) and Surface Area (acres)

Figure 2.4.c

Bowling Green Lakes
Water supply Study - Bowling Green, Missouri
Drought Assessment Analysis

I. Overview

Bowling Green is in Pike County in northeast Missouri (figure 3.1.a and 3.1.b). Bowling Green's water supply is met by two city owned reservoirs located approximately 1 and 2 miles east of Bowling Green. During drought periods they require making plans to obtain additional water from some other source. One possibility that has been considered is to run a pipeline to the Mississippi River, another source would be Mark Twain Reservoir.

The city began using water from the West Reservoir in 1990, following it's filling with water after construction. The older East Reservoir has been enlarged in recent years and the drainage area is small, resulting in recharge being slow. In order to capture some of the overflow from the West Lake the city has installed equipment to pump water from the West Lake to the East Lake. A motorized valve operates and directs the flow either to the water plant or to the East Lake. This means that water is pumped to the East Lake only when the plant is off. A 1500 gallons per minute pump is used for the water transfer. During a drought period this scheme would not provide an adequate water supply because there would not be enough runoff to provide overflow from the West Lake.

Historical demand on the reservoirs in 2000 was reported to be 216,450,000 gallons equaling 0.593 million gallons per day. Based on total storage, water demand for each of these two reservoir studies was distributed between both lakes so that 60 percent of the needs could be supplied by the east reservoir and 40 percent supplied by the west reservoir. Figure 3.2 illustrates historical water use for Bowling Green. The water use trend has been increasing at a rate of 3.2 percent per year.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

This analysis modeled each of the two reservoirs to show the water demand upon the Bowling Green water supply system. The two reservoirs must work in unison to meet the demand for Bowling Green. This model assumes the 'Normal' demand for Bowling Green is 0.593 million gallons per day and that water from the East Reservoir meets 60 percent of the demand and the West Reservoir meets 40 percent of the demand.

II. Drought Assessment Summary

The Bowling Green Reservoirs are at risk of not meeting the community's demand for water during times of drought without additional sources of water as demand increases. The 2004 demand on the reservoirs was approximately 0.617 million gallons per day. When this demand value is applied to the reservoirs during the drought of record in the 1950's, water supply would not meet this demand. The estimated optimum yield from Bowling Green's two reservoirs is 0.595 million gallons per day (figures 3.3.a and 3.3.b).

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake.

The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Bowling Green Reservoirs conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on February 24 and 25, 2005. Surface area of the lakes and associated storage volume capacities are illustrated in figure 3.4.a and 3.4.b.

<u>Bowling Green Reservoirs Physical Data</u>

East Reservoir				***West Reservoir***		
736	0.1	0.1		732	0.0	0.0
738	0.9	1.0		734	0.3	0.2
740	3.1	4.0		736	0.9	1.4
742	3.7	9.5		738	1.4	3.7
744	5.5	18.8		740	1.9	7.1
746	7.1	31.5		742	2.4	11.3
748	8.3	46.8		744	2.8	16.5
750	9.4	64.5		746	3.1	22.3
752	10.5	84.4		748	3.5	29.0
754	11.7	107		750	5.4	37.5
756	13.3	132		752	8.0	51.0
758	14.9	160		754	10.5	69.4
760	16.4	199		756	12.6	92.6
762	18.1	225		758	14.6	120
764	20.0	263		760	17.0	152
766	21.6	305		762	18.8	187
768	23.1	350		764	20.5	227
770	24.8	398		766	23.1	269
772	26.3	449		768	23.7	315
774	27.7	503		770	25.2	364
776	29.2	560		772	26.9	416
778	30.6	619		773.6	28.2	460
780	33.1	683				
782	33.6	748				
784	35.1	817				
786	36.6	888				
788	38.2	963				
790	39.9	1,040				
792	41.8	1,120				
794	44.0	1,210				
794.6	44.8	1,240				
Spillway Elevation = 794.6 feet <u>Water Surface on February 23, 2005</u> Elevation 794.6 feet				Spillway Elevation = 773.6 feet <u>Water Surface on February 24, 2005</u> Elevation 773.6 feet		

[LIMITS]
<u>East Reservoir</u>

Maximum storage……………………………………………………………….1240 acre-feet.
Minimum storage…………………………………………………………………50 acre-feet.
Drainage basin size……………………………………………………………803 acres.

West Reservoir

Maximum storage……………………………………………………………….……460 acre-feet.
Minimum storage……………………………………………………………………50 acre-feet.
Drainage basin size…………………………………………………………………809 acres.

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from West Lake is estimated to be 2.0 inches per month near full capacity and approaches 0.0 inches as the reservoir is emptied. Seepage from East Lake is estimated to be 3.5 inches per month at full capacity and approaches 0.0 as the reservoir empties. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible

[RAINFALL]

Precipitation values for the drought of record were obtained from the Bowling Green, Missouri rain gauge.

The most severe drought occurred between 1952 and 1957 with annual precipitation values in Bowling Green for the period of 1952 through 1957 of 25.48, 26.85, 28.39, 33.78, 29.47 and 39.53 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Young's Creek stream gauge, located at Mexico approximately 30 miles west of Bowling Green. The drainage area monitored by this stream gauge covers approximately 67.4 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Bowling Green, individual storm events were considered. Antecedent rainfall was determined for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

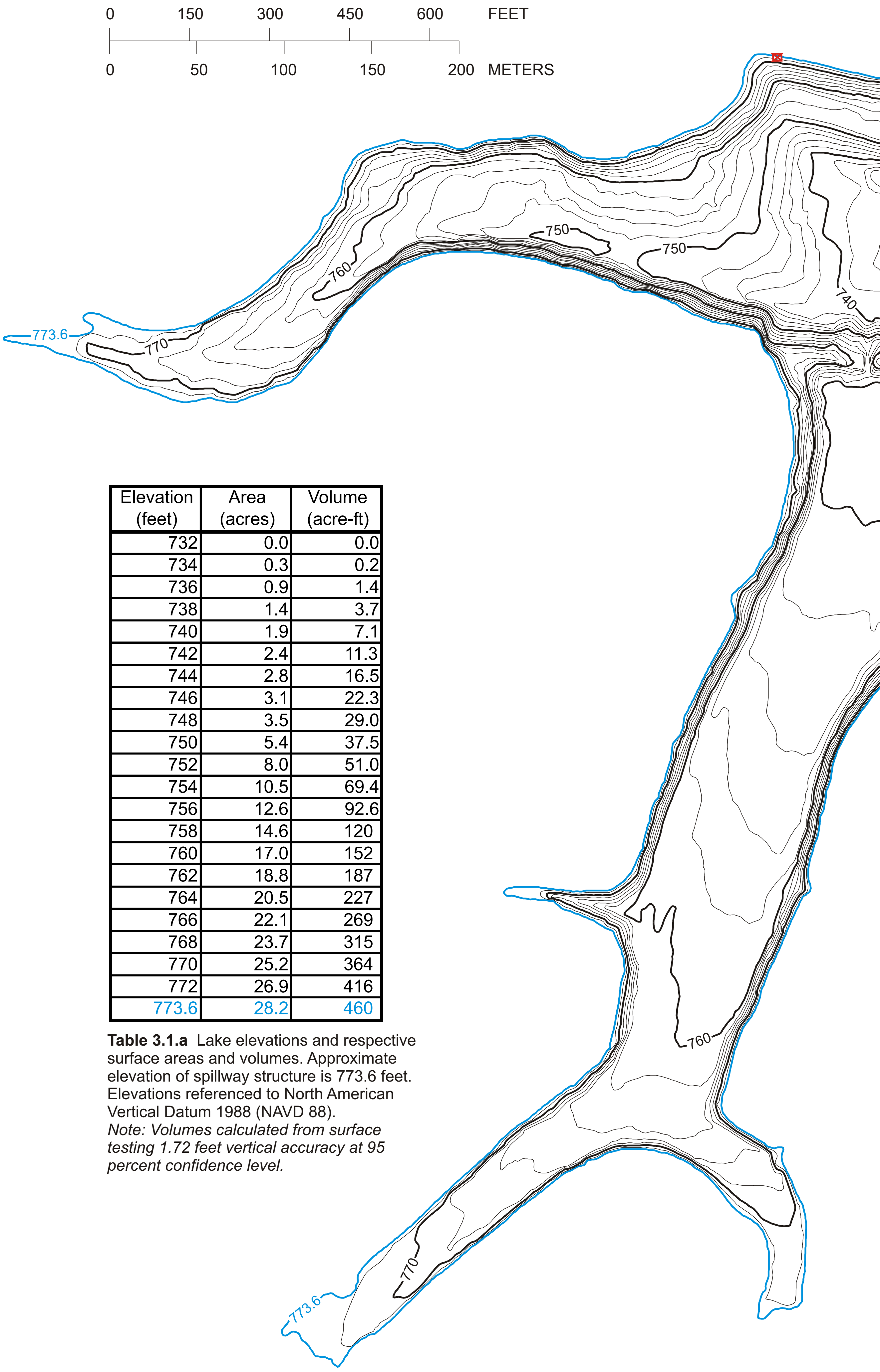
[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Bowling Green Reservoirs due to evaporation. This data was supplemented and compared with evaporation data from stations at New Franklin, Missouri or Washington University located in St. Louis, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert pan evaporation to lake evaporation.

[DEMAND]

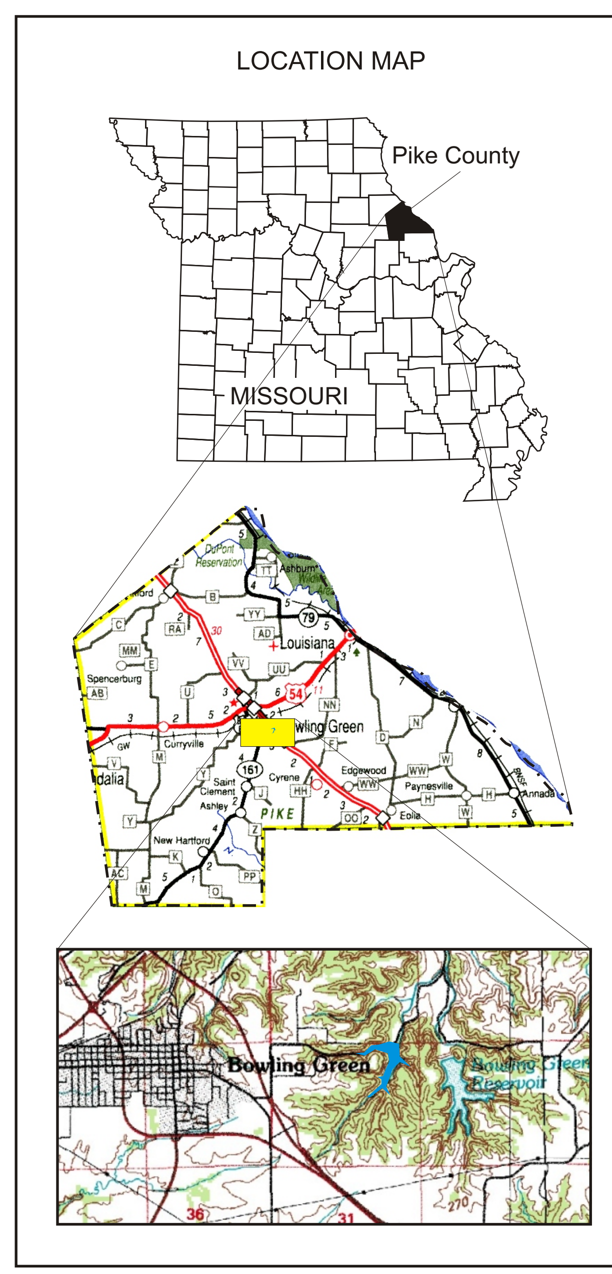
City records reported to "Missouri Department of Natural Resources" major water users database determined water demand. Bowling Green reported using a total of 216,450,000 gallons, averaging 0.593 million gallons per day of water in year 2000. To distribute water between the two lakes, It was determined that 60percent of demand could come from the East Lake because it has more storage volume and 40percent would come from the West Lake. The East Reservoir would supply 0.356 million gallons per day, and West Supplies 0.237 million gallons per day. These values were applied to the drought of record.

BOWLING GREEN (NEW) LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
732	0.0	0.0
734	0.3	0.2
736	0.9	1.4
738	1.4	3.7
740	1.9	7.1
742	2.4	11.3
744	2.8	16.5
746	3.1	22.3
748	3.5	29.0
750	5.4	37.5
752	8.0	51.0
754	10.5	69.4
756	12.6	92.6
758	14.6	120
760	17.0	152
762	18.8	187
764	20.5	227
766	22.1	269
768	23.7	315
770	25.2	364
772	26.9	416
773.6	28.2	460

Table 3.1.a Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 773.6 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.72 feet vertical accuracy at 95 percent confidence level.



EXPLANATION

—770— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Contours tested 2.44 feet vertical accuracy at 95 percent confidence level.

—773.6— WATER SURFACE—Shows elevation of water surface, February 24-25, 2005 (table 35).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on rip-rap boulder at northwest end of dam. Elevation 774.2 feet.

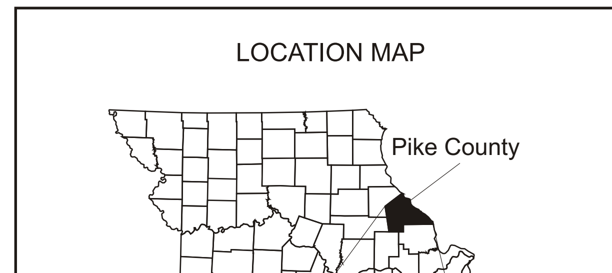
Figure 3.1.a

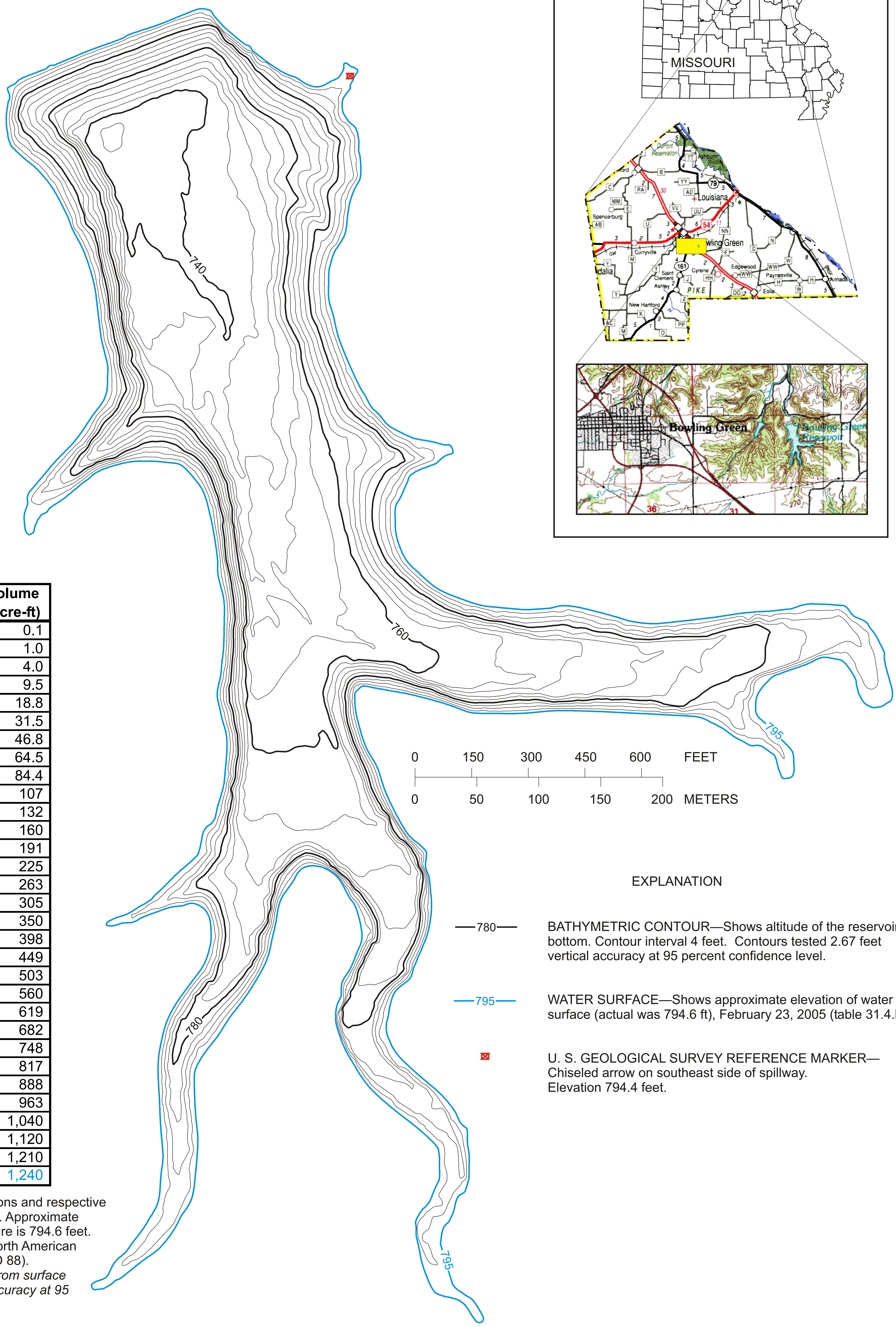
USGS
science for a changing world

map and table of areas/volumes of the Bowling Green (New) Lake near Bowling Green, Missouri.

In cooperation with Missouri Department of Natural Resources

BOWLING GREEN (OLD) RESERVOIR





Elevation (feet)	Area (acres)	Volume (acre-ft)
736.0	0.1	0.1
738.0	0.9	1.0
740.0	2.1	4.0
742.0	3.7	9.5
744.0	5.5	18.8
746.0	7.1	31.5
748.0	8.3	46.8
750.0	9.4	64.5
752.0	10.5	84.4
754.0	11.7	107
756.0	13.3	132
758.0	14.9	160
760.0	16.4	191
762.0	18.1	225
764.0	20.0	263
766.0	21.6	305
768.0	23.1	350
770.0	24.8	398
772.0	26.3	449
774.0	27.7	503
776.0	29.2	560
778.0	30.6	619
780.0	32.1	682
782.0	33.6	748
784.0	35.1	817
786.0	36.6	888
788.0	38.2	963
790.0	39.9	1,040
792.0	41.8	1,120
794.0	44.0	1,210
794.6	44.8	1,240

Table 3.1..b Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 794.6 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 2.28 feet vertical accuracy at 95 percent confidence level.

EXPLANATION

—780— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 4 feet. Contours tested 2.67 feet vertical accuracy at 95 percent confidence level.

—795— WATER SURFACE—Shows approximate elevation of water surface (actual was 794.6 ft), February 23, 2005 (table 31.4.b).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on southeast side of spillway. Elevation 794.4 feet.

Figure 3.1.b

USGS
science for a changing world

In cooperation with Missouri Department of Natural Resources

Bathymetric map and table of areas/volumes of the Bowling Green (Old) Reservoir near Bowling Green, Missouri.

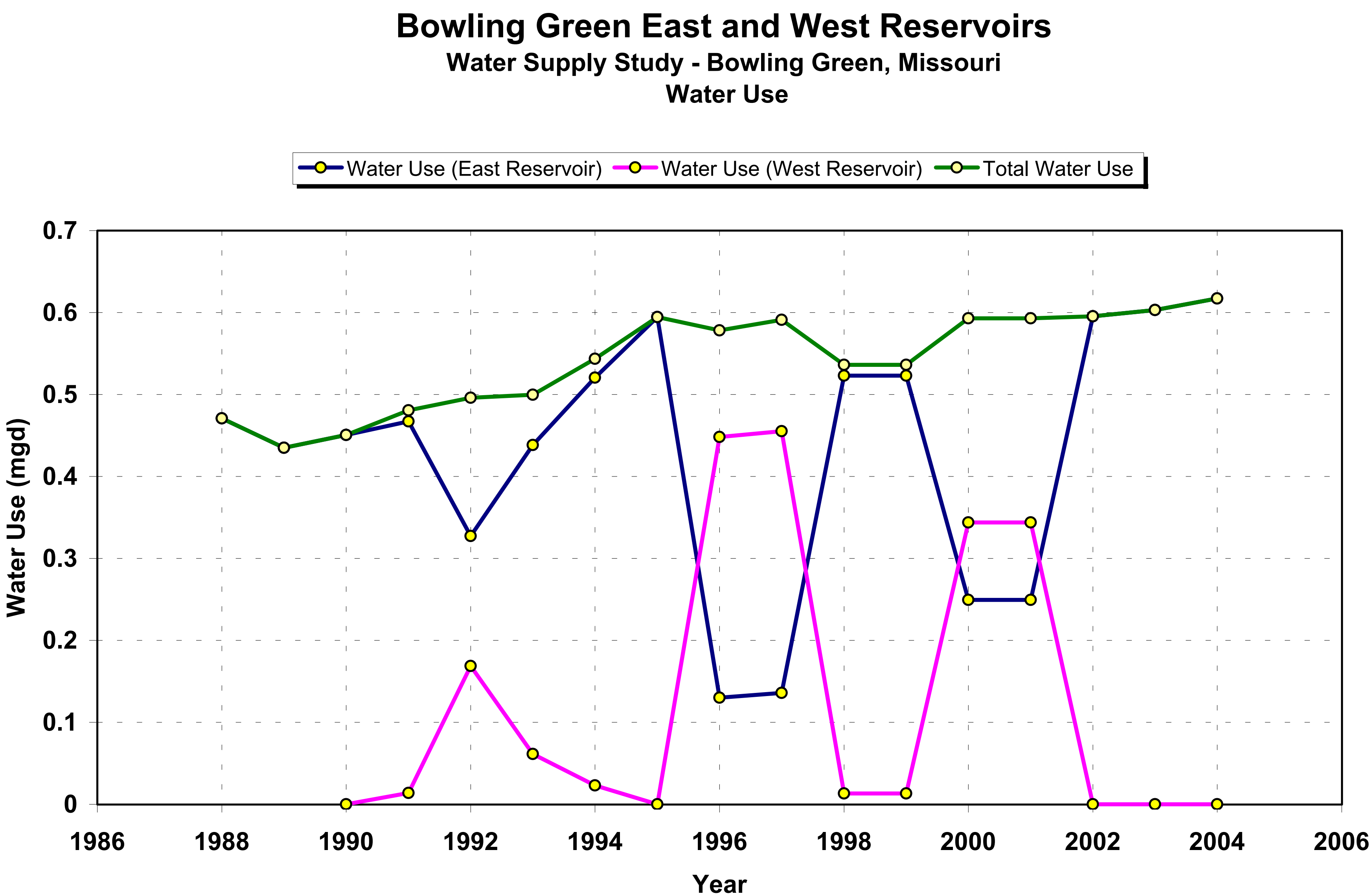

Bowling Green East and West Reservoirs
Water Supply Study - Bowling Green, Missouri
Water Use
Water Use (East Reservoir)
Water Use (West Reservoir)
Total Water Use
Water Use (mgd)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year

Figure 3.2

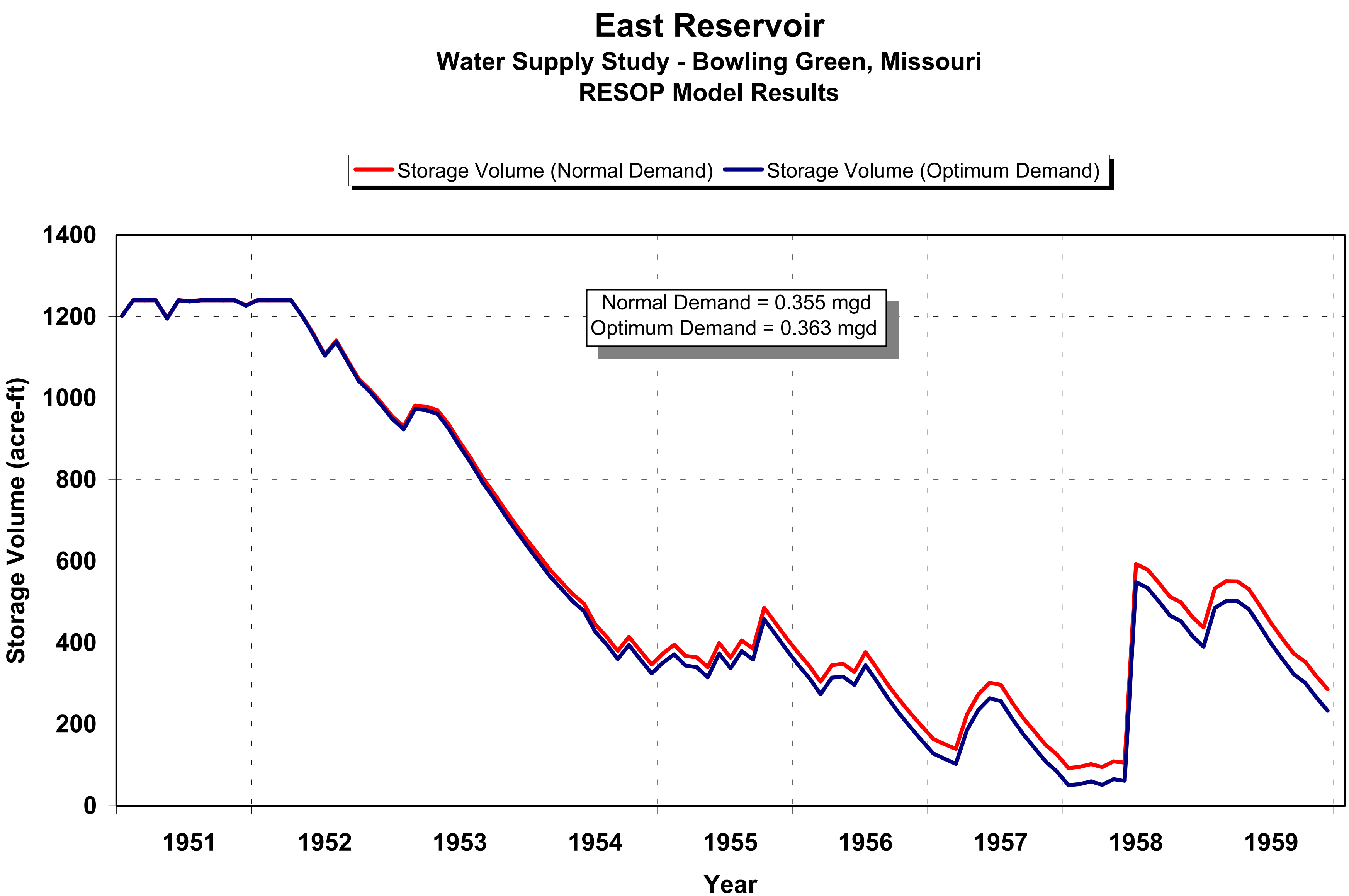

East Reservoir
Water Supply Study - Bowling Green, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 0.355 mgd
Optimum Demand = 0.363 mgd
Storage Volume (acre-ft)
1400
1200
1000
800
600
400
200
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 3.3.a

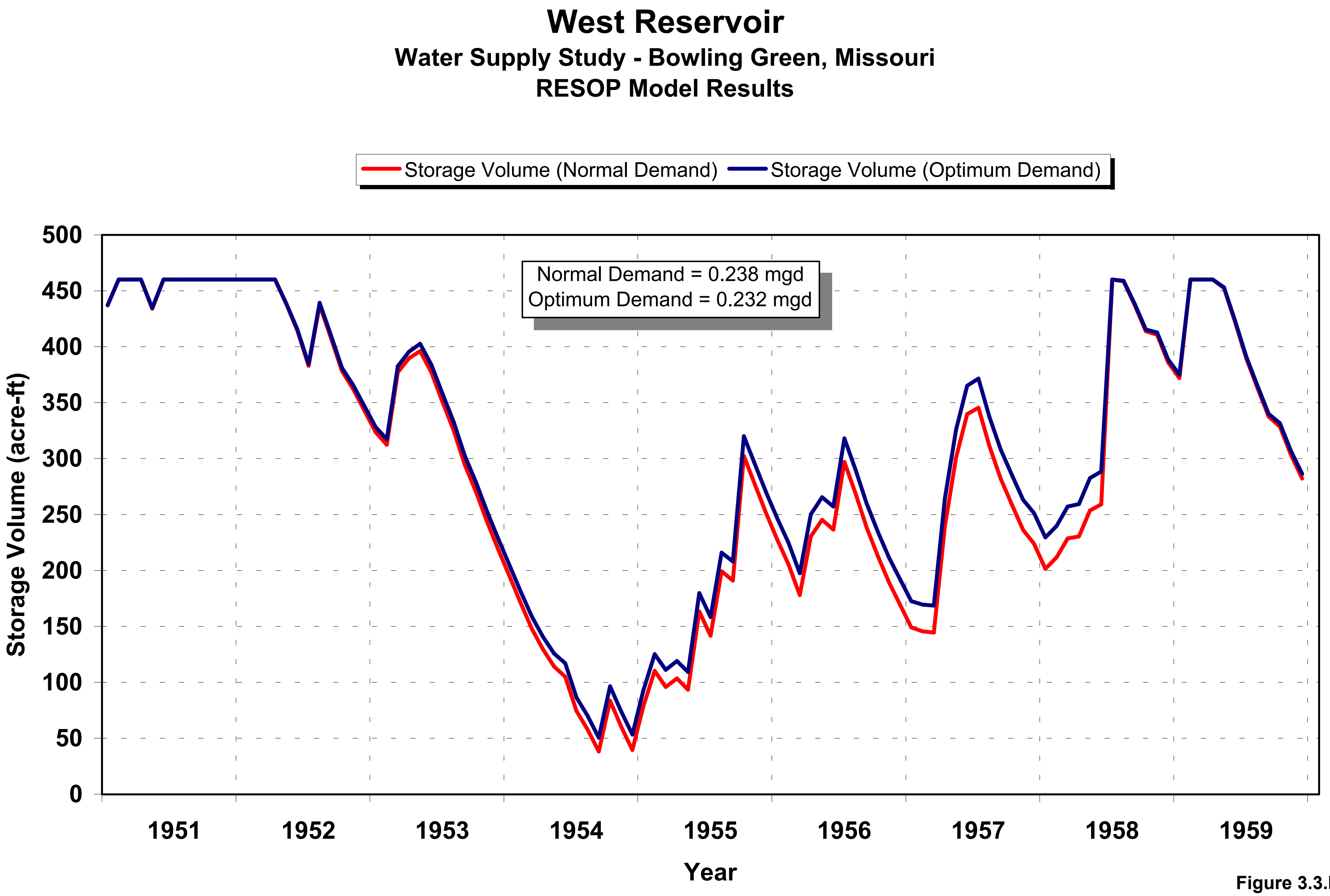

West Reservoir
Water Supply Study - Bowling Green, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 0.238 mgd
Optimum Demand = 0.232 mgd
Storage Volume (acre-ft)
0
50
100
150
200
250
300
350
400
450
500
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 3.3.b

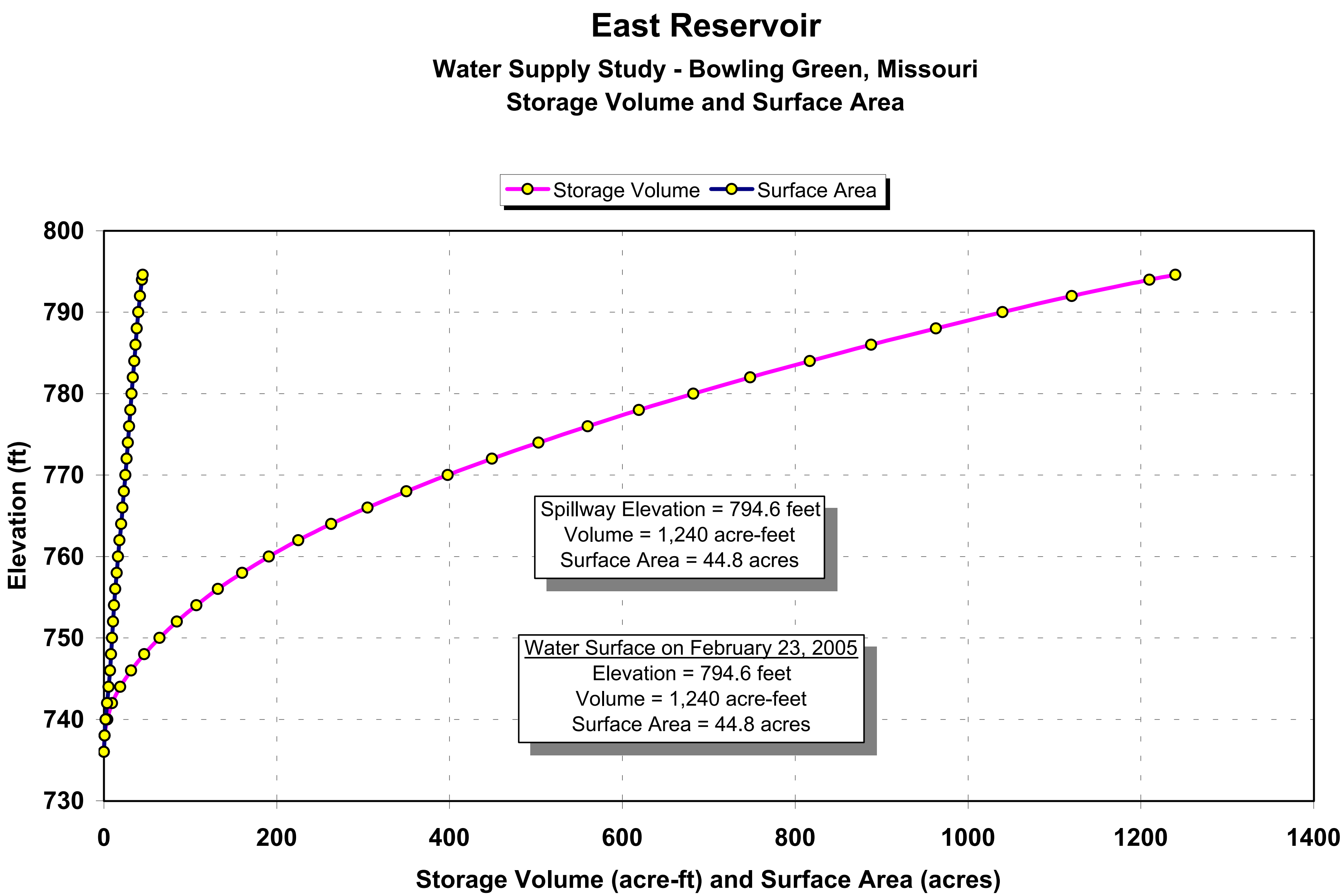

East Reservoir
Water Supply Study - Bowling Green, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Elevation (ft)
800
790
780
770
760
750
740
730
0
200
400
600
800
1000
1200
1400
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 794.6 feet
Volume = 1,240 acre-feet
Surface Area = 44.8 acres
Water Surface on February 23, 2005
Elevation = 794.6 feet
Volume = 1,240 acre-feet
Surface Area = 44.8 acres

Figure 3.4.a

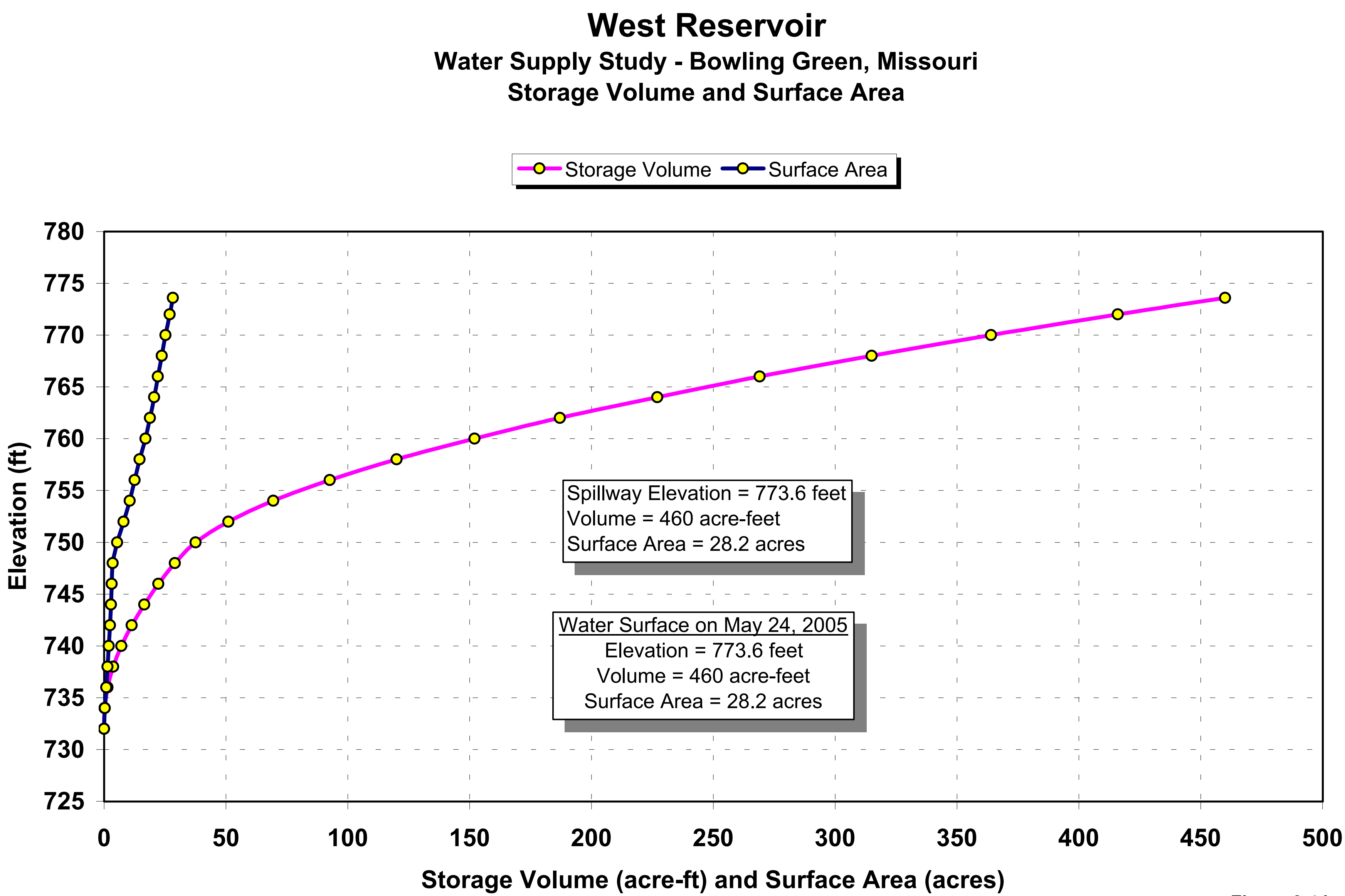

West Reservoir
Water Supply Study - Bowling Green, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 773.6 feet
Volume = 460 acre-feet
Surface Area = 28.2 acres
Water Surface on May 24, 2005
Elevation = 773.6 feet
Volume = 460 acre-feet
Surface Area = 28.2 acres
Elevation (ft)
Storage Volume (acre-ft) and Surface Area (acres)
780
775
770
765
760
755
750
745
740
735
730
725
0
50
100
150
200
250
300
350
400
450
500

Figure 3.4.b

Breckenridge Reservoir
Water Supply Study – Breckenridge, Missouri
Drought Assessment Analysis

I. Overview

Breckenridge Reservoir (figure 4.1) is located in northeastern Caldwell County, Missouri, less than one mile north of the City of Breckenridge. Breckenridge Reservoir is the primary source of water for the City of Breckenridge. The City of Breckenridge also sells finished water to Daviess County PWSD # 2, who, in turn, sells water to the City of Jameson. The Breckenridge Reservoir serves a population of approximately 1,242 with an estimated water demand of 0.059 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

The City of Breckenridge draws water directly from the reservoir to the treatment facility, and the reservoir, itself, can be supplemented with water from one groundwater well owned by the city. Historical demand on the reservoir in 2000 and 2001 was reported to be 45,000 gallons per day. Since 2004, water demand is reported to be 59,000 gallons per day, which is the demand value used in this model. Breckenridge is not considered a major water user. As a result they have not been reporting their historical water use to Missouri Department of Natural Resources. The Safe Drinking Water Information System (SDWIS) database indicates they are currently using an average of 59,000 gallon per day.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Breckenridge Reservoir. Although one groundwater well is available to supplement this water supply, the contribution of this well to available supplies was not considered within the context of this model. The model assumes that ‘Normal’ demand for Breckenridge is 59,000 gallons per day and that ‘Optimum’ yield from the lake is 52,000 gallons per day. Figure 4.3 illustrates these relationships.

II. Drought Assessment Summary

The Breckenridge Reservoir is at risk of not meeting the community’s demand for water during times of drought without additional sources of water. The 2004 demand on the reservoir was approximately 59,000 gallons per day, and when this demand value is applied to the reservoir during the drought of record in the 1950’s, water deficits would have occurred in August 1957 and between October 1957 through January 1958, and in April 1958. The estimated firm yield from Breckenridge Reservoir is 52,000 gallons per day without additional water sources. The groundwater well owned by the City of Breckenridge is capable of pumping up to 60 gallons per minute to supplement the reservoir’s storage capacity.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Breckenridge Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on April 5, 2004. Surface area of the lake and associated storage volume capacity are illustrated in figure 4.4.

Breckenridge Lake Physical Data

Breckenridge Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
780	0.3	0.1	
782	0.9	1.3	
784	1.4	3.7	
786	1.9	7	
788	2.5	11.3	
790	3	16.7	
792	3.7	23.3	
794	4.6	31.6	
796	5.6	41.8	
798	7	54.4	
800	8.3	69.6	
802	9.8	87.6	
806	13.7	130	Lake conditions April 5, 2004
806.5	14.3	140	Spillway
808	15.9	160	
809.4	17.7	190	Top of Dam

[LIMITS]

Maximum storage ....140 acre-feet
Minimum storage ....11.3 acre-feet
Drainage basin size .... 416 acres

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Breckenridge Lake is approximately 1.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Average precipitation in Breckenridge was 37.5 inches between 1970 and 2000. Precipitation values for the drought of record were obtained from Chillicothe, Missouri (approximately 12 mile east-northeast of Breckenridge). The most severe drought occurred between 1953 and 1957 with annual precipitation values in Chillicothe of 20.07 inches, 33.55 inches, 28.27 inches, 27.88 inches, and 42.38 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Jenkins Branch at Gower MO (USGS 06821000) stream gauge (a tributary of the Platte River), located approximately 35 miles west of Breckenridge. The drainage area monitored by this stream gauge covers approximately 2.72 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Breckenridge, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

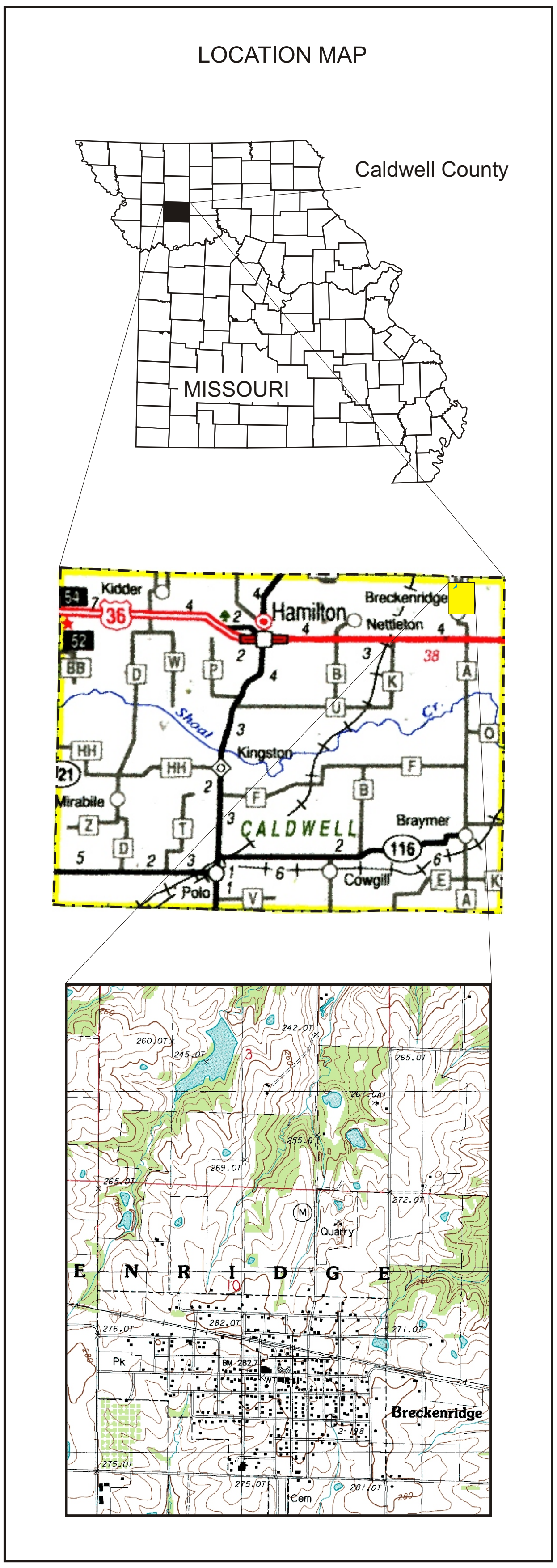
[EVAP]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Breckenridge Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

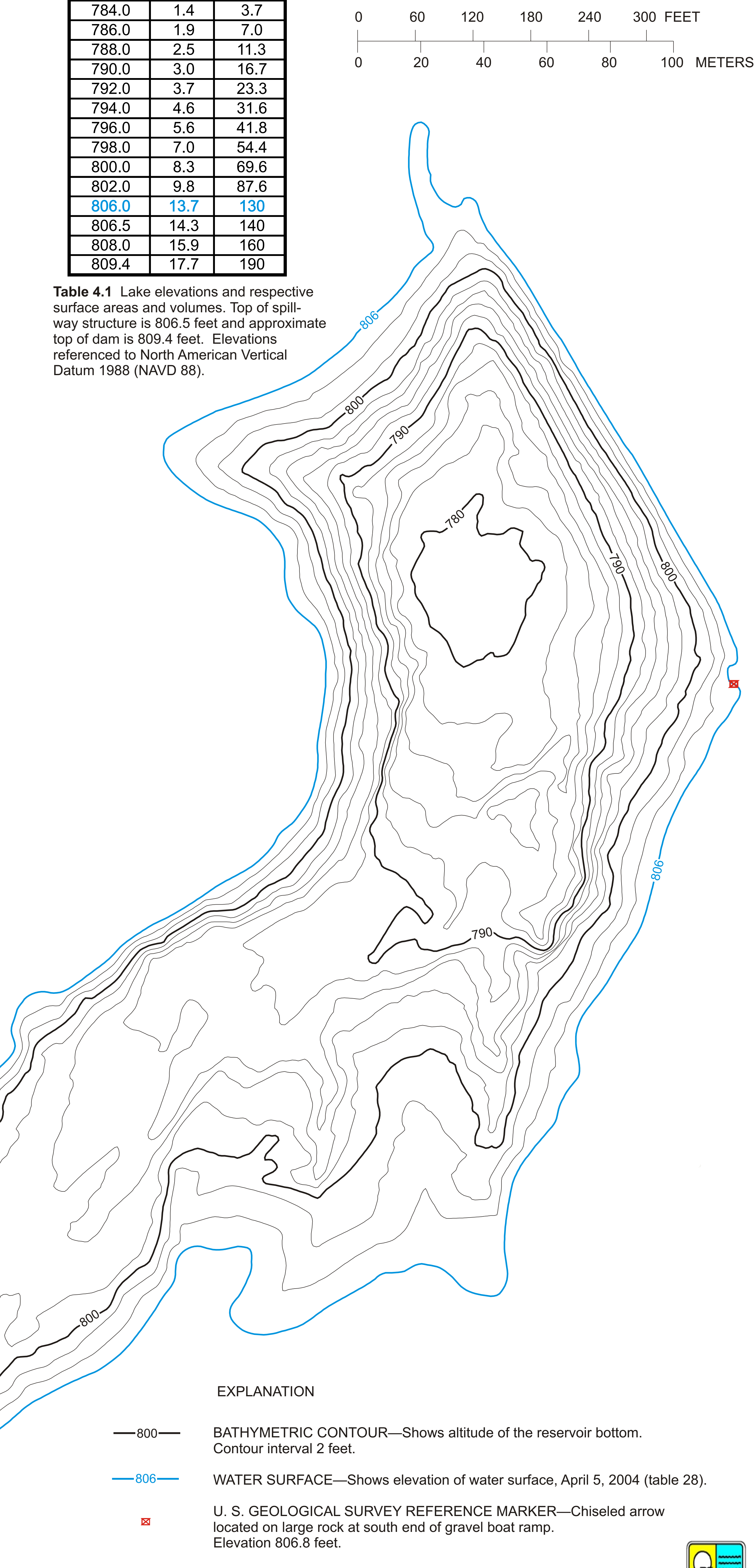
Water demand for Breckenridge was obtained from records maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources. This value has been constant at 59,000 gallons per day since 2004 and is the demand applied to the record of drought in this model.

BRECKENRIDGE LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
780.0	0.3	0.1
782.0	0.9	1.3
784.0	1.4	3.7
786.0	1.9	7.0
788.0	2.5	11.3
790.0	3.0	16.7
792.0	3.7	23.3
794.0	4.6	31.6
796.0	5.6	41.8
798.0	7.0	54.4
800.0	8.3	69.6
802.0	9.8	87.6
806.0	13.7	130
806.5	14.3	140
808.0	15.9	160
809.4	17.7	190

Table 4.1 Lake elevations and respective surface areas and volumes. Top of spillway structure is 806.5 feet and approximate top of dam is 809.4 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).



EXPLANATION

800 BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

806 WATER SURFACE—Shows elevation of water surface, April 5, 2004 (table 28).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on large rock at south end of gravel boat ramp. Elevation 806.8 feet.

Figure 4.1

Figure 4.1 Bathymetric map and table of areas/volumes of the Breckenridge Lake near Breckenridge, Missouri.

In cooperation with Missouri Department of Natural Resources

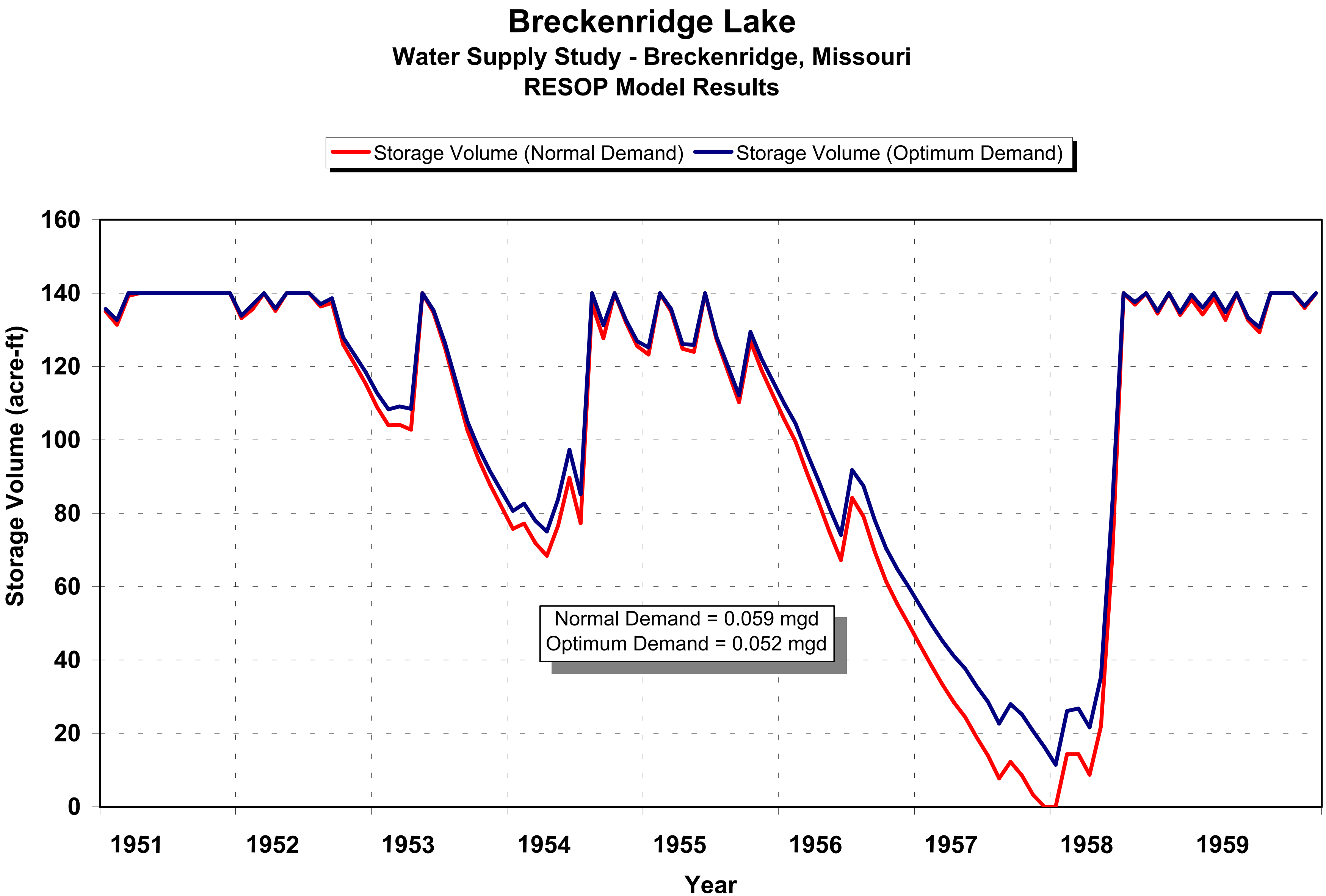

Breckenridge Lake
Water Supply Study - Breckenridge, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 0.059 mgd
Optimum Demand = 0.052 mgd
Storage Volume (acre-ft)
0
20
40
60
80
100
120
140
160
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 4.3

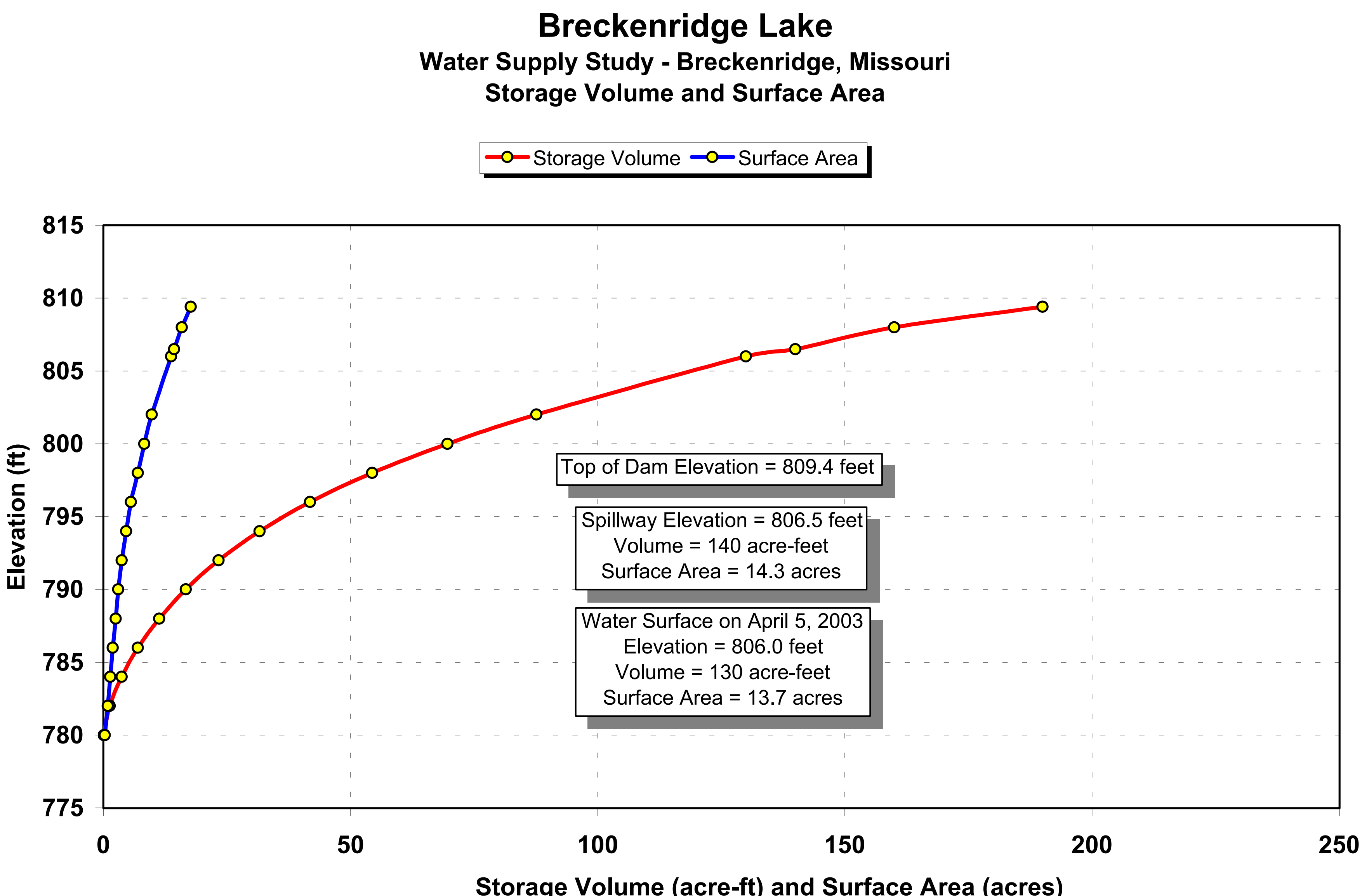

Breckenridge Lake
Water Supply Study - Breckenridge, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Elevation (ft)
815
810
805
800
795
790
785
780
775
0
50
100
150
200
250
Storage Volume (acre-ft) and Surface Area (acres)
Top of Dam Elevation = 809.4 feet
Spillway Elevation = 806.5 feet
Volume = 140 acre-feet
Surface Area = 14.3 acres
Water Surface on April 5, 2003
Elevation = 806.0 feet
Volume = 130 acre-feet
Surface Area = 13.7 acres

Figure 4.4

Brookfield Reservoir
Water Supply Study – Brookfield, Missouri
Drought Assessment Analysis

I. Overview

Brookfield Reservoir is located about 1.3 miles east of the city of Brookfield in the center of Linn County (figure 5.1). The primary source of water supply for Brookfield is diverting from West Yellow Creek. The plan is to pump 1500 gallons per minute from the creek into holding ponds located in the West Yellow Creek flood plain. There are 3 of these ponds, each an estimated 10-feet deep with surface areas of 17 acres, 7 acres and 8.5 acres. These ponds are kept full because the creek often has no flow during dry weather. Brookfield Reservoir has a small drainage area of 650 acres, too small to supply the lake with enough runoff for an adequate water supply, which serves a population of 4888 inhabitants. To be assured of adequate supply during a drought the city pumps from West Yellow Creek into the lake. Two pumps, each with 1000 gallons per minute (gpm) pumping capacity, are used to fill the lake. When the creek does not have enough flow to fill the holding ponds, the reservoir is used to fill the holding ponds at the rate of 1000 gallon per minute. The combined population served by the Brookfield reservoir system is approximately 4,888 with an average consumption of 0.675 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). Figure 5.2 illustrates water use for each year.

Determination of flows in West Yellow Creek that allow for pumping for this analysis were obtained from the Locust Creek stream gauge at Linneus for the 1950's. Average daily flows were reduced by the ratio of drainage areas. Seven cubic feet per second (cfs) for in-stream flow needs were allowed to pass downstream before pumping. The next 3.34-cfs was used to pump into the ponds, the next 4.45 cfs was pumped to the lake. This analysis is for the lake only and does not attempt to evaluate stream flow for West Yellow Creek.

The lake intake is a floating intake. It connects to the raw water piping on a concrete pillar that is roughly 3 feet above the original bottom of the lake. This raw water line passes through the dam to the lake pumping station on the downstream side of the dam. The intake can draw water over a 40 feet range. The spillway crest is a concrete ogee crest that is level and in good shape.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

This analysis consisted of four scenarios. The optimum RESOP analysis with the starting water elevation at the spillway elevation yielded an average of 0.230-million gallons per day (figure 5.3). For a conservative analysis the next three scenarios began with the water level three feet below the spillway. First an optimum analysis without water from West Yellow Creek yielding 0.207 million gallons per day. Second was an optimum analysis with input from West Yellow Creek by using two 1000 gallons per minute pumps yielding 0.617 million gallons per day. Third included a variable demand on the lake to keep the holding ponds near full after filling the ponds from West Yellow Creek. Using water from the holding ponds and the lake allowed Brookfield's average current demand of near 0.7 million gallons per day to be met with approximately 500 acre-feet of water remaining in the reservoir.

II. Drought Assessment Summary

The Brookfield Reservoir, by itself is not able to meet community's demand for water during times of drought without additional sources of water. The demand from Brookfield Reservoir varies each month to maintain a full supply to meet city demand. Average annual demand between 1988 and 2004 has varied between 0.6 and 0.7 million gallons per day. The 2002 demand can be met by using all their capabilities to supply water for their use. This analysis indicates there is no room for expansion of the system's ability to supply water at the 2004 use of 0.675 million gallons per day.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Brookfield Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on July 13, 2000. Surface area of the lake and associated storage volume capacities are illustrated in figure 5.4.

Brookfield Reservoir Physical Data

Brookfield Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
768	2.2	1.5	
770	6.6	10.5	
772	11.0	27.9	
774	16.5	55.2	
776	23.7	95.3	
778	29.8	149.0	
780	36.8	215.3	
782	43.1	295.6	
784	49.6	387.9	
786	57.1	494.6	
788	65.0	616.7	
790	72.9	754.4	
792	81.8	908.8	
794	90.1	1081.2	
795.8	97.1	1249.7	Water Conditions on July 12, 2000
796	98.0	1269.2	
797	102.6	1369.5	
798	107.4	1474.4	
800	117.4	1699.0	
802	125.6	1942.3	
803	130.7	2070.3	Spillway

[LIMITS]

Maximum storage ....2070 acre-feet
Minimum storage ....55 acre-feet
Drainage basin size ....650 acres

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Brookfield Reservoir is estimated to be approximately 3.5 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation values for the drought of record were obtained from Brookfield gauge.

Average precipitation in Brookfield was 38.9 inches between 1950 and 2000. The most severe drought occurred between 1953 and 1957 with annual precipitation values of 27.56 inches, 38.71 inches, 34.05 inches, 23.36 inches, and 48.20 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Locust Creek stream gauge at Linneus. The drainage area monitored by this stream gauge covers approximately 550 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Brookfield, individual storm events were considered. Antecedent rainfall was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Brookfield Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

Water demand was obtained from records reported by the city to Missouri Department of Natural Resources "Major Water Users Data Base" (figure 5.2).

Brookfield water demand has averaged between 0.6 and 0.7 mg day since 1988. Water demand from Brookfield Reservoir and West Yellow Creek are reported separately. Brookfield has been reporting approximately 25 percent of their water coming from West Yellow Creek and 75 percent from their reservoir.

To establish the monthly demand for the lake, an analysis of the holding ponds was made to determine the volume of additional water that would be required to meet Brookfield's needs. Requirements varied each month.

[OTHER]

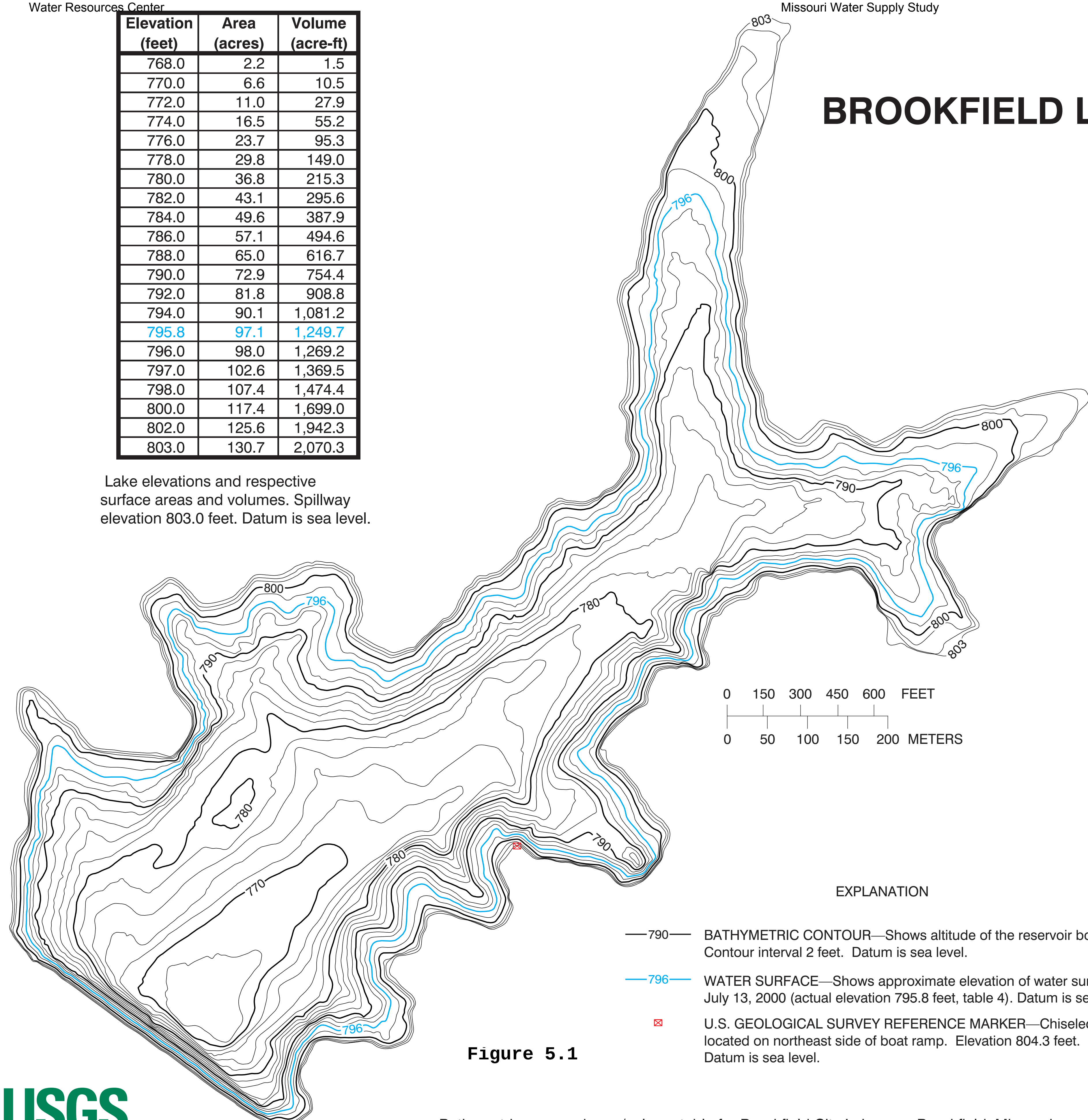
The volume of water pumped from West Yellow Creek to Brookfield Reservoir. Determination of the volume of water available for pumping was made using daily discharges at the Locust Creek stream gage at Linneus. The drainage area at Linneus is 550 square miles and the drainage area for West Yellow Creek at the point of pumping is 159 square miles. The daily discharge rates in West Yellow Creek were reduced by the ratio of drainage areas. Pumping was only planned for stream flows above 10.34 cfs, 7 cfs, for in-stream flow requirements plus 1500 gallons per minute, (3.34 cfs) for pumping to the ponds.

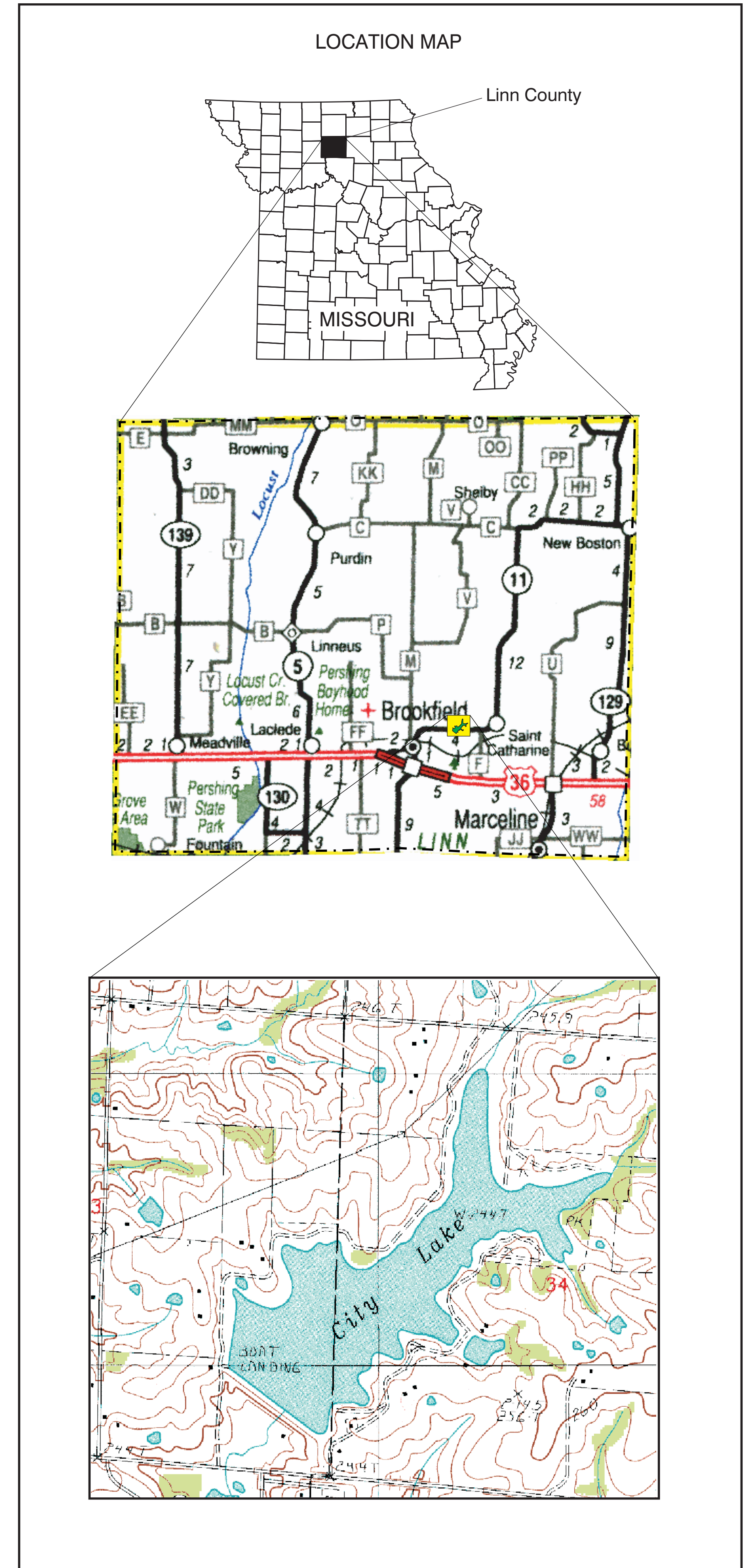
To pump water to the reservoir a pumping rate of 2000 gallons per minute, (4.45 cfs), was planned after stream flow reached 14.79 cfs. No pumping was used when there was spillage from the reservoir.

Elevation (feet)	Area (acres)	Volume (acre-ft)
768.0	2.2	1.5
770.0	6.6	10.5
772.0	11.0	27.9
774.0	16.5	55.2
776.0	23.7	95.3
778.0	29.8	149.0
780.0	36.8	215.3
782.0	43.1	295.6
784.0	49.6	387.9
786.0	57.1	494.6
788.0	65.0	616.7
790.0	72.9	754.4
792.0	81.8	908.8
794.0	90.1	1,081.2
795.8	97.1	1,249.7
796.0	98.0	1,269.2
797.0	102.6	1,369.5
798.0	107.4	1,474.4
800.0	117.4	1,699.0
802.0	125.6	1,942.3
803.0	130.7	2,070.3

Lake elevations and respective surface areas and volumes. Spillway elevation 803.0 feet. Datum is sea level.

BROOKFIELD LAKE





EXPLANATION

—790— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—796— WATER SURFACE—Shows approximate elevation of water surface, July 13, 2000 (actual elevation 795.8 feet, table 4). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on northeast side of boat ramp. Elevation 804.3 feet. Datum is sea level.

Figure 5.1

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Bathymetric map and area/volume table for Brookfield City Lake near Brookfield, Missouri.

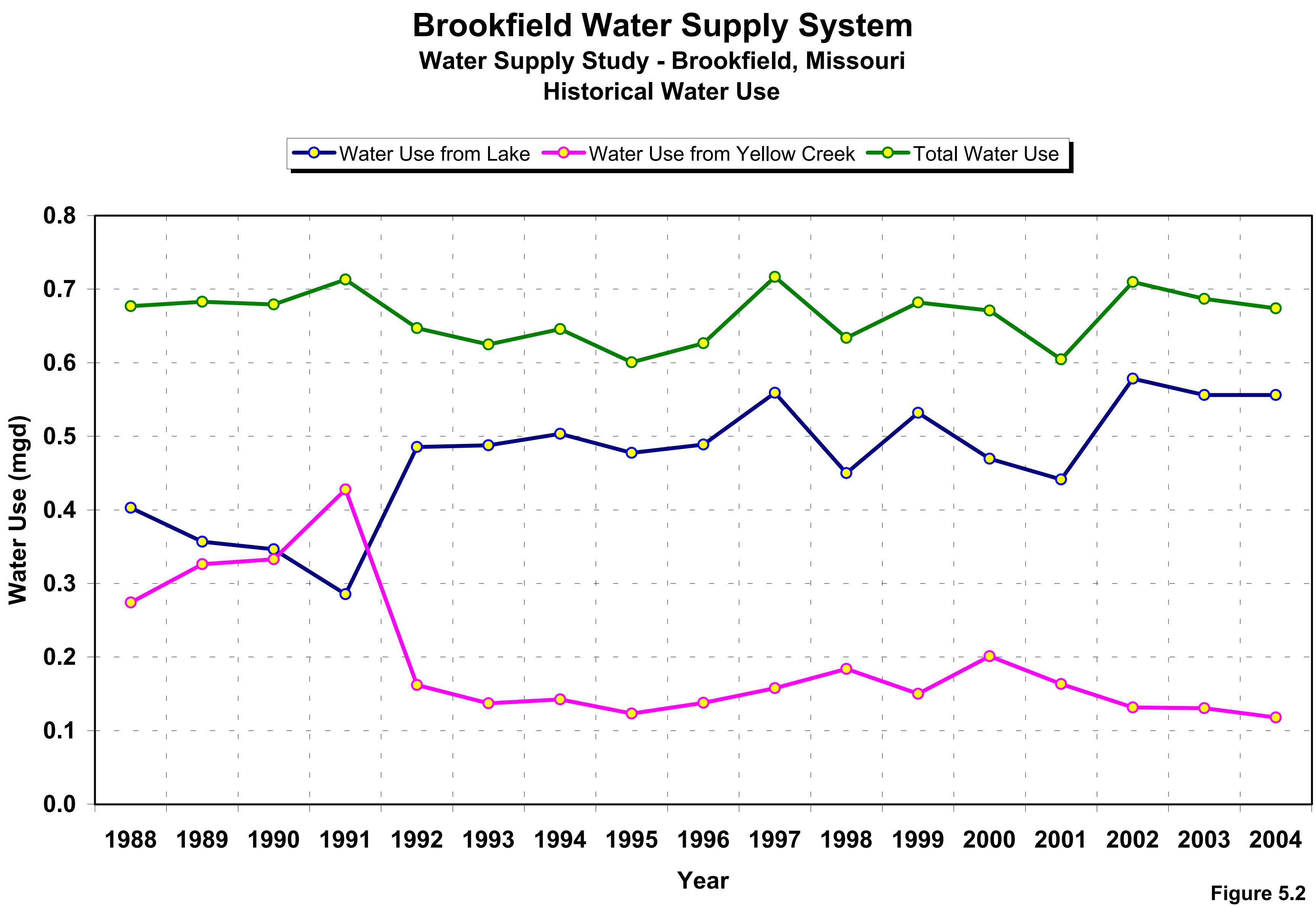

Brookfield Water Supply System
Water Supply Study - Brookfield, Missouri
Historical Water Use
Water Use from Lake
Water Use from Yellow Creek
Total Water Use
Water Use (mgd)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Year

Figure 5.2

BROOKFIELD LAKE

Water Supply Study - Brookfield, Missouri
RESOP Model Results

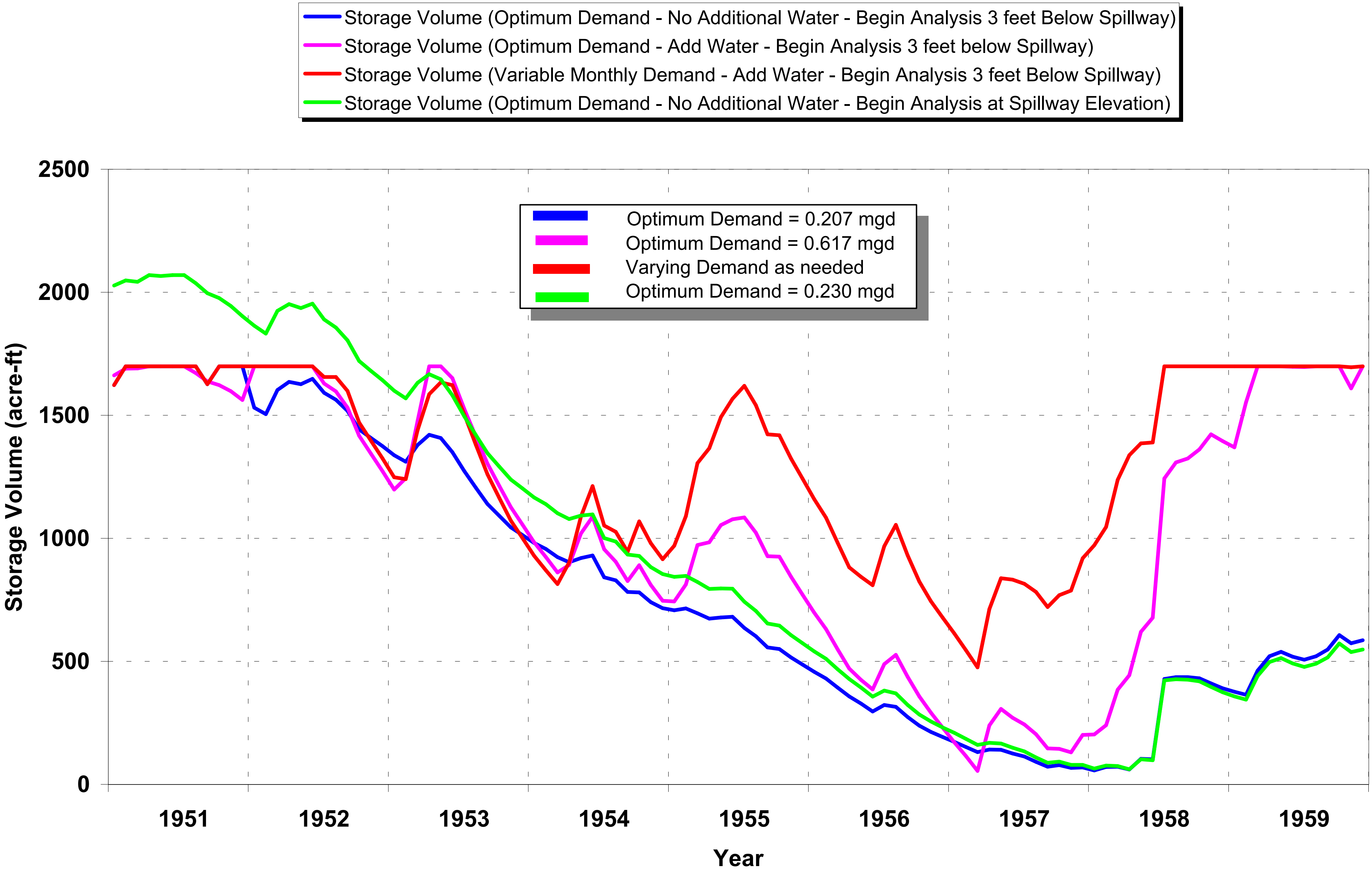


Figure 5.3

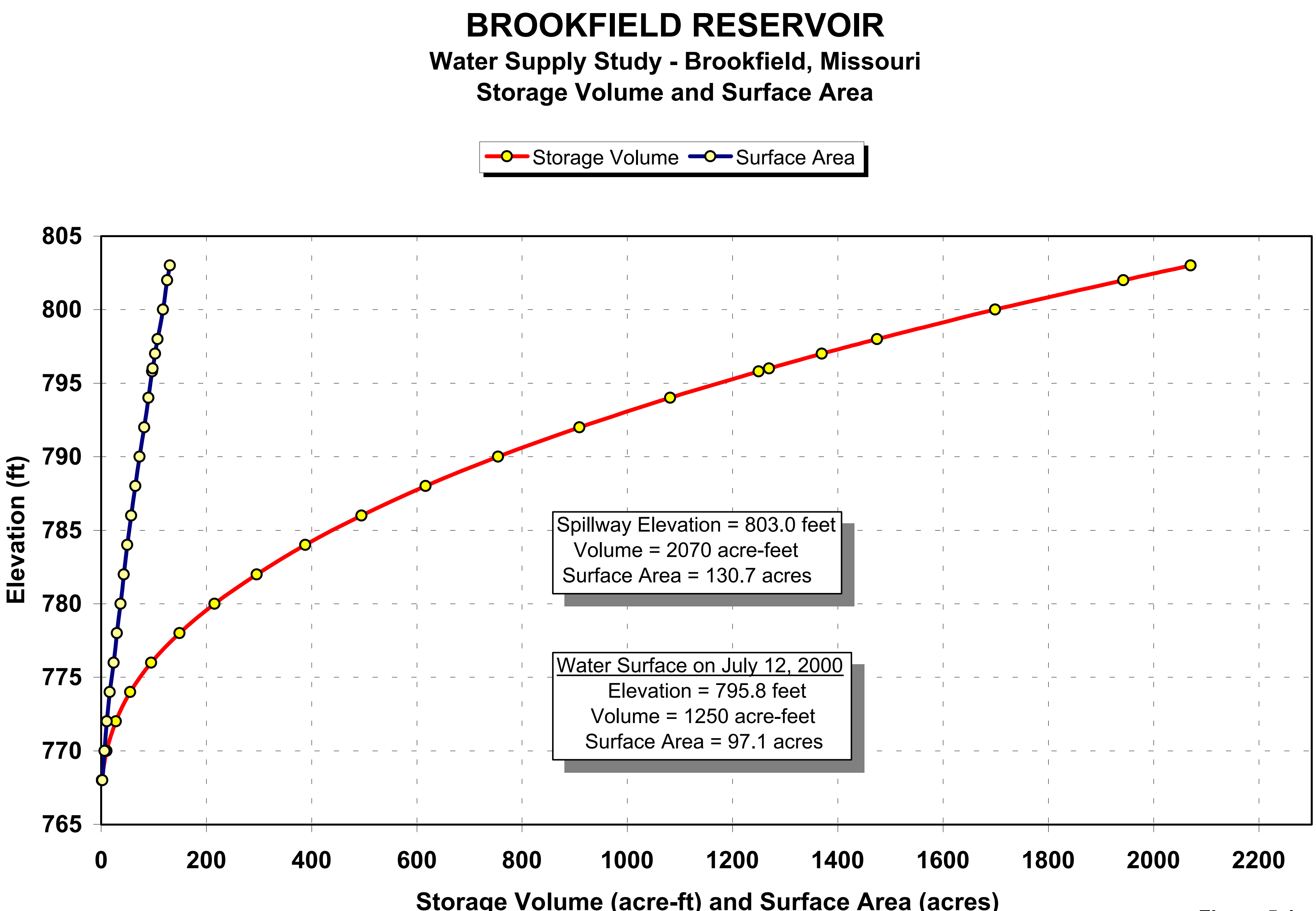

BROOKFIELD RESERVOIR
Water Supply Study - Brookfield, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
805
800
795
790
785
780
775
770
765
Elevation (ft)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 803.0 feet
Volume = 2070 acre-feet
Surface Area = 130.7 acres
Water Surface on July 12, 2000
Elevation = 795.8 feet
Volume = 1250 acre-feet
Surface Area = 97.1 acres

Figure 5.4

Bucklin Reservoir
Water Supply Study – Bucklin, Missouri
Drought Assessment Analysis

I. Overview

Bucklin Lake (figure 6.1) is located at the eastern edge of Linn County approximately 5 miles North and 2 Miles East of Marceline, or eight miles East of Brookfield. Bucklin Lake is on Van Dorsan Creek, a tributary to Mussel Fork Creek. The lake is located one-half mile south of Bucklin, in the center of section 11. Bucklin Lake is the primary source of water for the city. Because of the inability of the lake to store enough water during dry periods and because of the small drainage area it is necessary to pump from Mussel Fork Creek into the lake when flow in the creek is adequate.

Bucklin Reservoir provides some water to Chariton-Linn County Public Water Supply District (PWSF) #3. The combined population served by Bucklin is approximately 524 with an average consumption of 0.085 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). The drainage area to the lake is 300 acres. The volume of lake storage is approximately 156 acre-feet with a surface area of about 20 acres.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Two scenarios were modeled for Bucklin Reservoir. The model assumes that 'Normal' demand for Bucklin is 0.085 million gallons per day and that 'Optimum' yield from the lake is 0.046 million gallons per day. By using a 400 gallons per minute pump water is diverted from Mussel Fork Creek to the Bucklin Reservoir. Figure 6.3 illustrates these relationships.

II. Drought Assessment Summary

This analysis shows that the lake, by itself, does not have enough storage volume to provide a continuous water supply to meet Bucklin's needs. It is necessary to attempt to keep the lake full if they are to maintain a dependable water supply during dry periods. This study shows that without pumping from the creek, the lake would be completely empty during 1956 and 1957. It is necessary to have the lake full going into these dry periods to provide water to their residents. Approximately 45 acre-feet of water would remain in the lake.

To meet the normal demand of 0.085 million gallons per day without pumping from Mussel Fork Creek the lake would be empty for the years of 1956 and 1957. Optimized demand would yield only an average of 46,000 gallons per day. By pumping from Mussel Fork Creek the 85,000 gallons per day could be met (figure 6.3).

III. RESOP model parameters

Terms in brackets (and bold print) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol

for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Bucklin Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on March 19, 2007. Surface area of the lake and associated storage volume capacity are illustrated in figure 6.4

Bucklin Lake Physical Data

Bucklin Lake

Elevation (feet)	Area (acres)	Volume (acre-feet)	
830	2.0	1.7	
832	3.9	8.0	
834	6.6	18.0	
836	9.6	34.3	
838	12.1	56.1	
840	14.7	82.7	
842	17.8	115.6	
844	19.5	152.9	
844.2	19.8	156.8	Spillway and lake conditions on March 19, 2007

[LIMITS]

Maximum storage……………………………………………………………156.8 acre-feet
Minimum storage…………………………………………………………..26 acre-feet

Initial storage volume was equated to the lake volume at ‘maximum storage.’

The drainage area of Bucklin Lake is 300 acres.

[GENERAL]

The record period of drought is in the 1950's. The analysis began in January 1951 and ended December 1959.

[SEEPAGE]

Seepage from Bucklin Lake is estimated to be 2.5 inches per month when at or near full capacity and near 0.0 inches when the lake is near empty. The lake is bound by an earthen dam composed of compacted clay-rich materials-seepage through the dam is considered minimal.

[RAINFALL]

Rainfall data came from the Brookfield, Missouri rain gage.

Average annual rainfall for the last 50 years is 38.8 inches at Brookfield. The most severe drought occurred between 1951 through 1959. Annual rainfall during the drought period 1953 through 1957 was 27.6, 38.7, 34.1, 23.4, and 48.2 inches.

Average annual rainfall for the last 50 years is 38.8 inches at Brookfield. The most severe drought occurred between 1951 through 1959. Annual rainfall during the drought period 1953 through 1957 was 27.6, 38.7, 34.1, 23.4, and 48.2 inches.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from Locust Creek gauge near Linneus. When this regional runoff value is inconsistent with precipitation values for Bucklin, daily precipitation rates were considered. Antecedent rainfall was used to estimate soil moisture for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS's) runoff curve number were made to estimate runoff from each storm event (see appendix A for additional information).

[EVAP.]

Pan evaporation data from Lakeside gauging station (near the Lake of the Ozarks) was used to estimate water loss from Bucklin Lake due to evaporation. This data was supplemented and compared with evaporation stations at Spickard, New Franklin, and Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation values.

[DEMAND]

Water demand for Bucklin was obtained from Missouri water supply census of 2007. City records reported using 85,000 gallons per day in year 2007.

[OTHER]

Additional water added to Bucklin Lake by pumping from Mussel Fork Creek.

Stream flow data for Locust Creek at Linneus was used as a basis to determine average daily stream discharge. Daily values were adjusted based on the drainage area ratio. To determine the rate of steam flow available for pumping, the 7-day Q-10 low flow discharge was used to determine the in-stream flow needs before pumping was possible. The 7-day Q-10 low flow discharge was based on the Mussel Fork Creek gauge for the period 1963 through 1989 when data was available. This discharge was determined to be less than 1 cubic foot per second, as a result 1 cubic feet per second was used. Assuming the pump is able to operate one half the time and flow in the creek exceeds 1.9 cubic feet per second the city could expect to meet their demand. The intake point is east of Bucklin where a 400 gallons per minute pump is installed.

Drainage area of Mussel Fork at pumping location is approximately 62 square miles

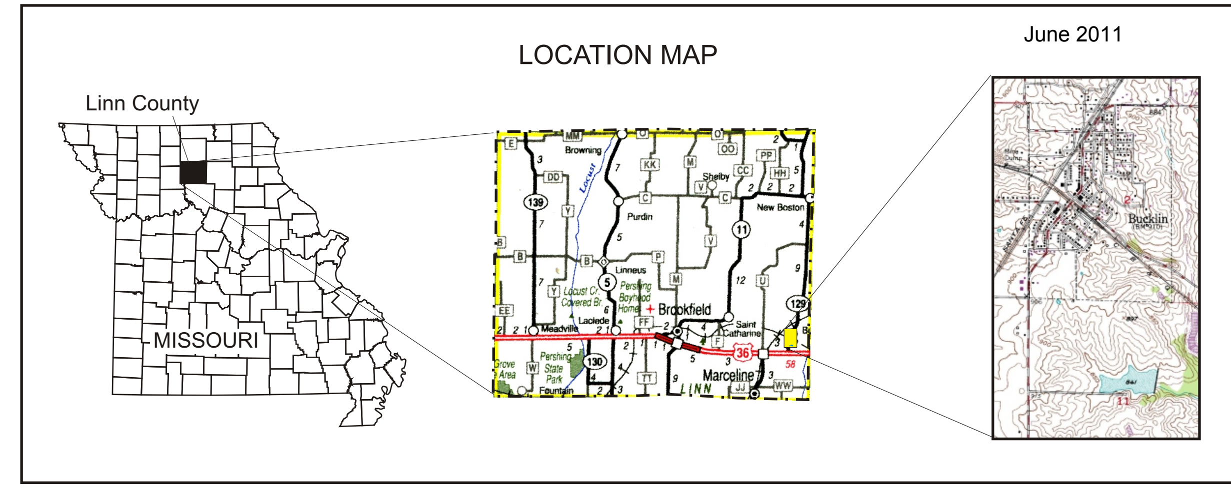
Missouri Department of Natural Resources
Water Resources Center

Missouri Water Supply Study

BUCKLIN LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
830.0	2.0	1.7
832.0	3.9	8.0
834.0	6.6	18.0
836.0	9.6	34.3
838.0	12.1	56.1
840.0	14.7	82.7
842.0	17.8	115.6
844.0	19.5	152.9
844.2	19.8	156.8

Table 6.1 Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 844.2 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.28 feet vertical accuracy at 95 percent confidence level.

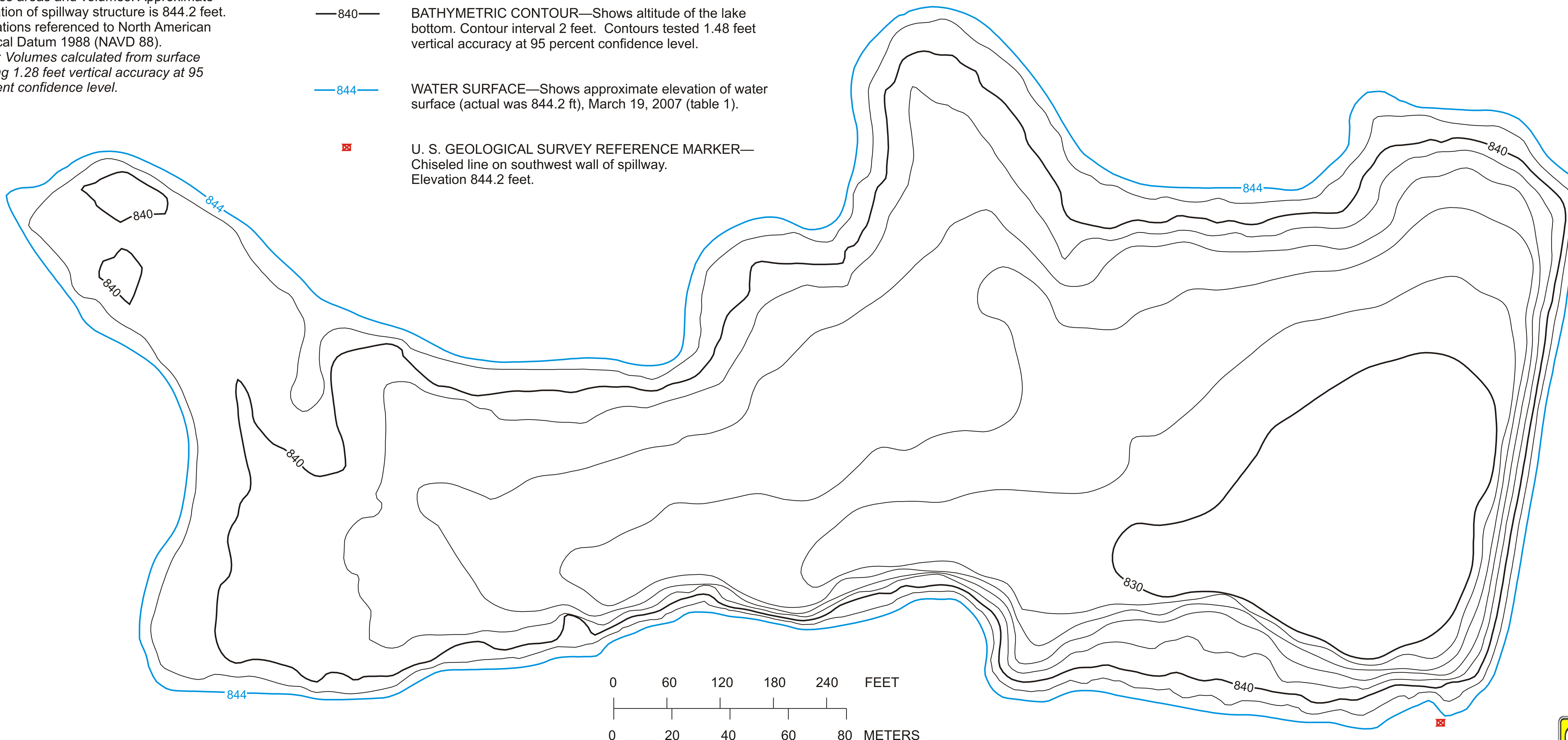


EXPLANATION

—840— BATHYMETRIC CONTOUR—Shows altitude of the lake bottom. Contour interval 2 feet. Contours tested 1.48 feet vertical accuracy at 95 percent confidence level.

—844— WATER SURFACE—Shows approximate elevation of water surface (actual was 844.2 ft), March 19, 2007 (table 1).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled line on southwest wall of spillway. Elevation 844.2 feet.



USGS
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map and table of areas/volumes of the Bucklin Lake near Bucklin, Missouri.

Figure 6.1

In cooperation with
Missouri Department
of Natural Resources

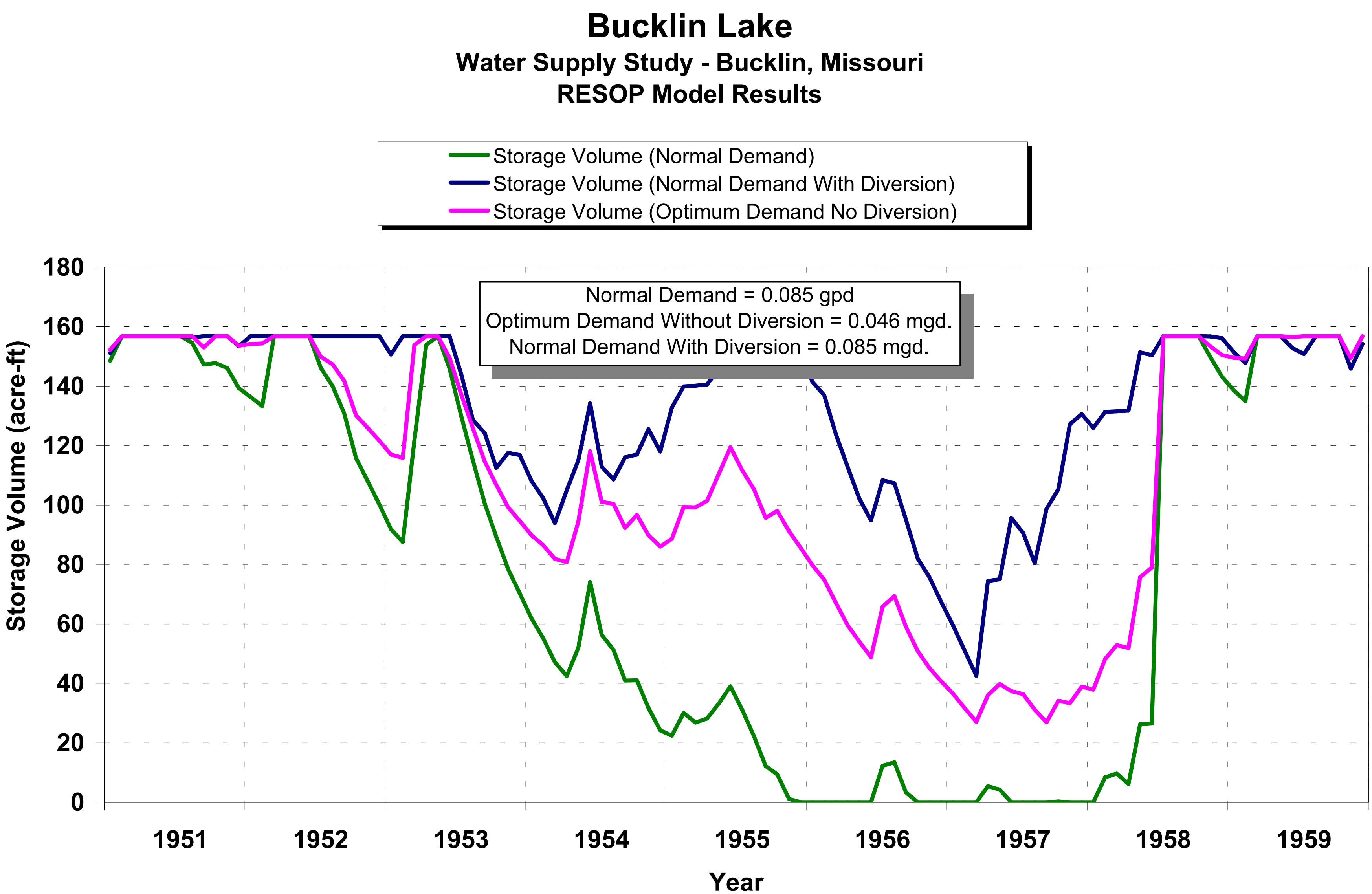

Bucklin Lake
Water Supply Study - Bucklin, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Normal Demand With Diversion)
Storage Volume (Optimum Demand No Diversion)
Normal Demand = 0.085 gpd
Optimum Demand Without Diversion = 0.046 mgd.
Normal Demand With Diversion = 0.085 mgd.
Storage Volume (acre-ft)
180
160
140
120
100
80
60
40
20
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 6.3

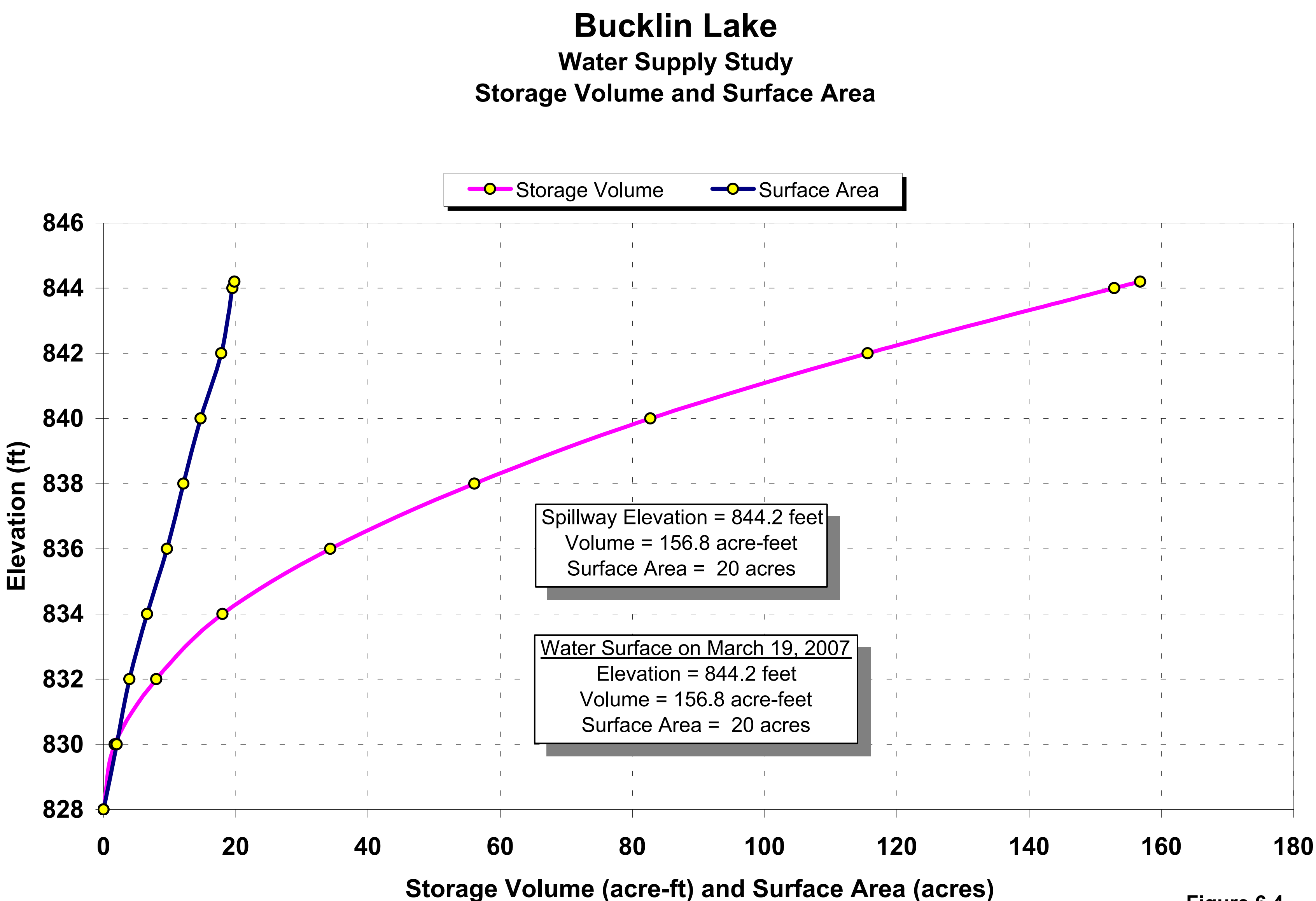

Bucklin Lake
Water Supply Study
Storage Volume and Surface Area
Storage Volume
Surface Area
846
844
842
840
838
836
834
832
830
828
Elevation (ft)
Spillway Elevation = 844.2 feet
Volume = 156.8 acre-feet
Surface Area = 20 acres
Water Surface on March 19, 2007
Elevation = 844.2 feet
Volume = 156.8 acre-feet
Surface Area = 20 acres
0
20
40
60
80
100
120
140
160
180
Storage Volume (acre-ft) and Surface Area (acres)

Figure 6.4

Butler Reservoir
Water Supply Study – Butler, Missouri
Drought Assessment Analysis

I. Overview

Butler Reservoir is located on a tributary to Miami Creek (figure 7.1), about 3 miles WSW of Butler. The lake has a drainage area of 3.11 Square Miles. Butler is approximately 55 miles south of Kansas City in Bates County. Up to January 2002, Butler has used three raw water sources. These are Miami Creek, Butler Lake, and Marais Des Cygnes River. During the year 2002, Butler completed a new pumping plant on the Marais Des Cygnes River. This plant has two 2000 gallons per minute pumps. One will be kept in reserve. Miami Creek will be taken off the system, in part because of high concentrations of agricultural chemicals. Butler supplies water to Bates PWSD's numbers 1, 3, 4 and 6. The combined population served by the Butler reservoir system is approximately 4,100 with an average consumption of 0.869 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). Figure 7.2 illustrates Butler historic water use.

The Marais Des Cygnes River diversion and the lake will be the sources of water supply for Butler. Pumping from the Marais Des Cygnes River is shut off when the atrazine chemical levels exceed drinking water standards, primarily during April through June. Marais Des Cygnes River water will be pumped into the Butler Lake for storing and will then be fed to the treatment plant by gravity flow at up to 1100 gallons per minute. The drainage area at the intake point on Marais Des Cygnes River is 3418 square miles.

For this study, pumping was planned so that the lake level does not fall below 5 to 6 feet below the spillway in order to have a minimum reserve of 400 acre-feet. This study does not consider pumping from mid-March through mid-July of each year. Pumping over the last several years has been necessary 4 to 5 months a year. Upstream dams and water uses in Kansas are intensively allocated at other upstream locations for municipal needs, wetland augmentation and cooling for power generation plants.

Upper limits of water available for use from the Marais Des Cygnes River, by Butler, on a monthly basis, was determined by use of a computer program, called STELLA. STELLA is a computer software tool for understanding dynamic systems of the natural hydrologic environment.

As part of this study it was found to be beneficial to analyze base flow and runoff indexes. This was done for the State Line Gauge on the Marais Des Cygnes River. The USGS computer program "HYSEP" was used to make this determination. The sliding hydrograph separation method was used. It generates median values of fixed and local hydrograph separation methods. This analysis was made for the period of record from 1959 through 2000. The results of those runs reflect a trend that the base flow is increasing over the evaluation period (figure 7.5). Figure 7.6 illustrates the annual volume of water that would be diverted from Marias Des Cygnes River during the evaluation period.

II. Drought Assessment Summary

The Butler Reservoir, by itself, cannot meet the community's demand for water without additional sources of water. Additional water is now diverted from Marais Des Cygnes River. Butler's 2000 demand was approximately 1.01 million gallons per day. Optimum demand from the reservoir, without additional input, is 0.27 million gallons per day. It would have been necessary to divert water from Marais Des Cygnes River a total of 43 percent of the total months of the evaluation period to maintain a minimum of 400 acre feet in the reservoir (figure 7.3).

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Butler Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on April 18, 2001. Surface area of the lake and associated storage volume capacity is illustrated in figure 7.4.

Butler Reservoir Physical Data

Butler Reservoir			
Elevation (feet)	Area (Acres)	Volume (acre-feet)	Additional Notes
770	0.74	0.57	
772	2.18	3.42	
774	3.63	9.26	
776	6.67	19.10	
778	12.66	37.68	
780	18.75	69.11	
782	27.70	112.18	
784	31.33	168.24	
786	37.82	237.08	
788	44.43	319.21	
790	54.24	417.02	
792	63.17	535.91	
794	69.88	668.82	
794.3	71.74	689.95	Lake Conditions April 18, 2001
795.1	74.80	748.60	Spillway
796	77.99	817.32	
798	85.22	980.40	
800	96.48	1159.77	Top of Dam

[LIMITS]

Maximum Storage……………………………………………………………….748.56 acre-feet.
Minimum Pool storage…………………………………………………………..15 acre-feet.
Drainage Basin Size…………………………………………………………3.11 square miles.

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Butler Reservoir is estimated to be approximately 3.5 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation values for the drought of record were obtained from Butler, Missouri

Average annual precipitation in Butler was 41.60 inches between 1961 and 2000. The most severe drought occurred between 1952 and 1957 with annual precipitation values in Butler of 28.86 inches, 27.14 inches, 36.02 inches, 40.68 inches, 24.40 inches and 39.57 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Little Blue River stream gauge near Lake City, North of Butler. Another regional stream gauge for Cedar Creek near pleasant View, Missouri was used for comparison. Results compared favorably. Based on topography, vegetation and soils Little Blue River gauge was chosen to represent Butler Reservoir runoff. When regional runoff value is inconsistent with precipitation values recorded for Butler, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Butler Reservoir due to evaporation. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

The demand used for Butler Reservoir analysis was 1.01 million gallons per day.

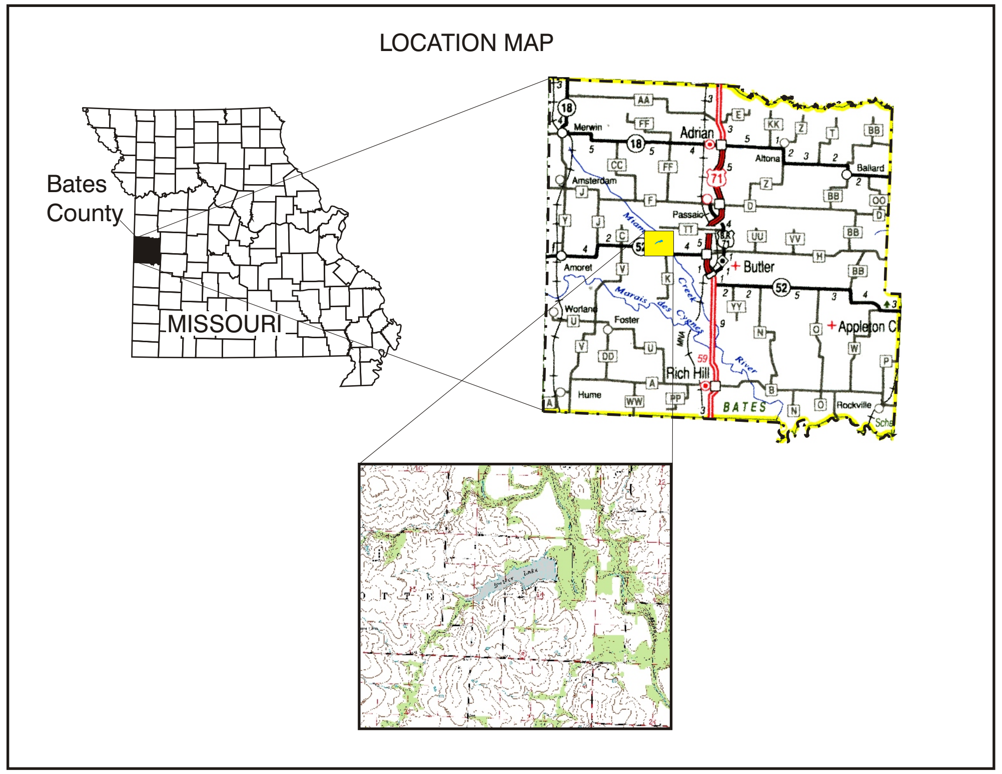
City records reported to Missouri Department of Natural Resources 'Major water users data base' were used to determined demand (figure 5.2). In year 2000 Butler reported using 1.01 million gallons per day of water.

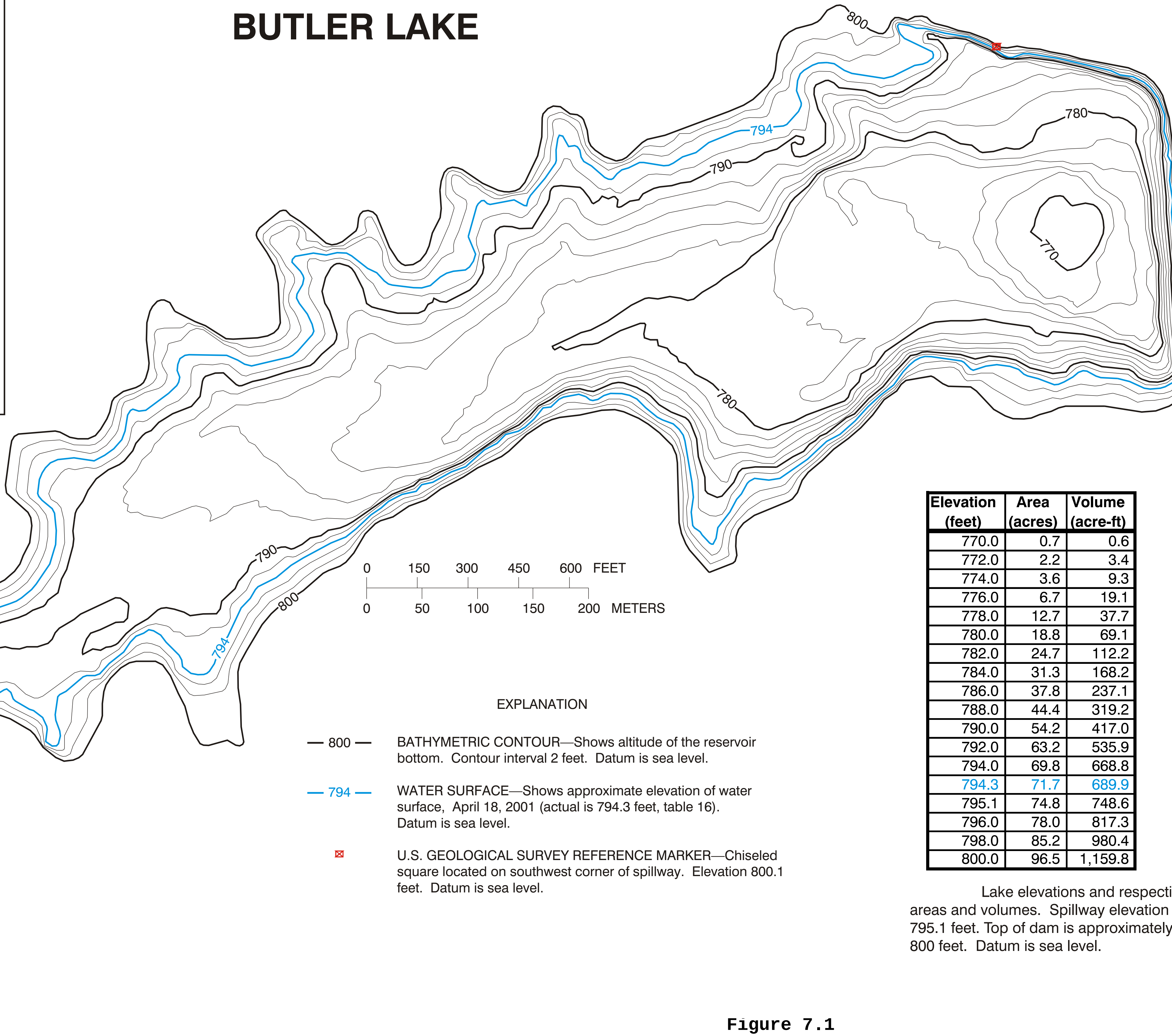
[OTHER]

When water level dropped to 5 feet below the spillway level, water was diverted to the lake from Marais Des Cygnes River.

Determination of the volume of water available for pumping was made using monthly discharge volumes determined by the Computer program, STELLA. The STELLA analysis was based on the stream gauge data at Trading Post Gauge (drainage area 3230 square miles) and factored up based on drainage area. Pumping is timed so that water level does not go below 5 to 6 feet below spillway at approximately 400 acre-feet at elevation 789.7 feet. Pumping in each month is either 0% of the time, 1/2 time, 3/4 time or full time

BUTLER LAKE





Elevation (feet)	Area (acres)	Volume (acre-ft)
770.0	0.7	0.6
772.0	2.2	3.4
774.0	3.6	9.3
776.0	6.7	19.1
778.0	12.7	37.7
780.0	18.8	69.1
782.0	24.7	112.2
784.0	31.3	168.2
786.0	37.8	237.1
788.0	44.4	319.2
790.0	54.2	417.0
792.0	63.2	535.9
794.0	69.8	668.8
794.3	71.7	689.9
795.1	74.8	748.6
796.0	78.0	817.3
798.0	85.2	980.4
800.0	96.5	1,159.8

Lake elevations and respective areas and volumes. Spillway elevation is 795.1 feet. Top of dam is approximately 800 feet. Datum is sea level.

Figure 7.1

Bathymetric map and table of areas/volumes of Butler Lake near Butler, Missouri.

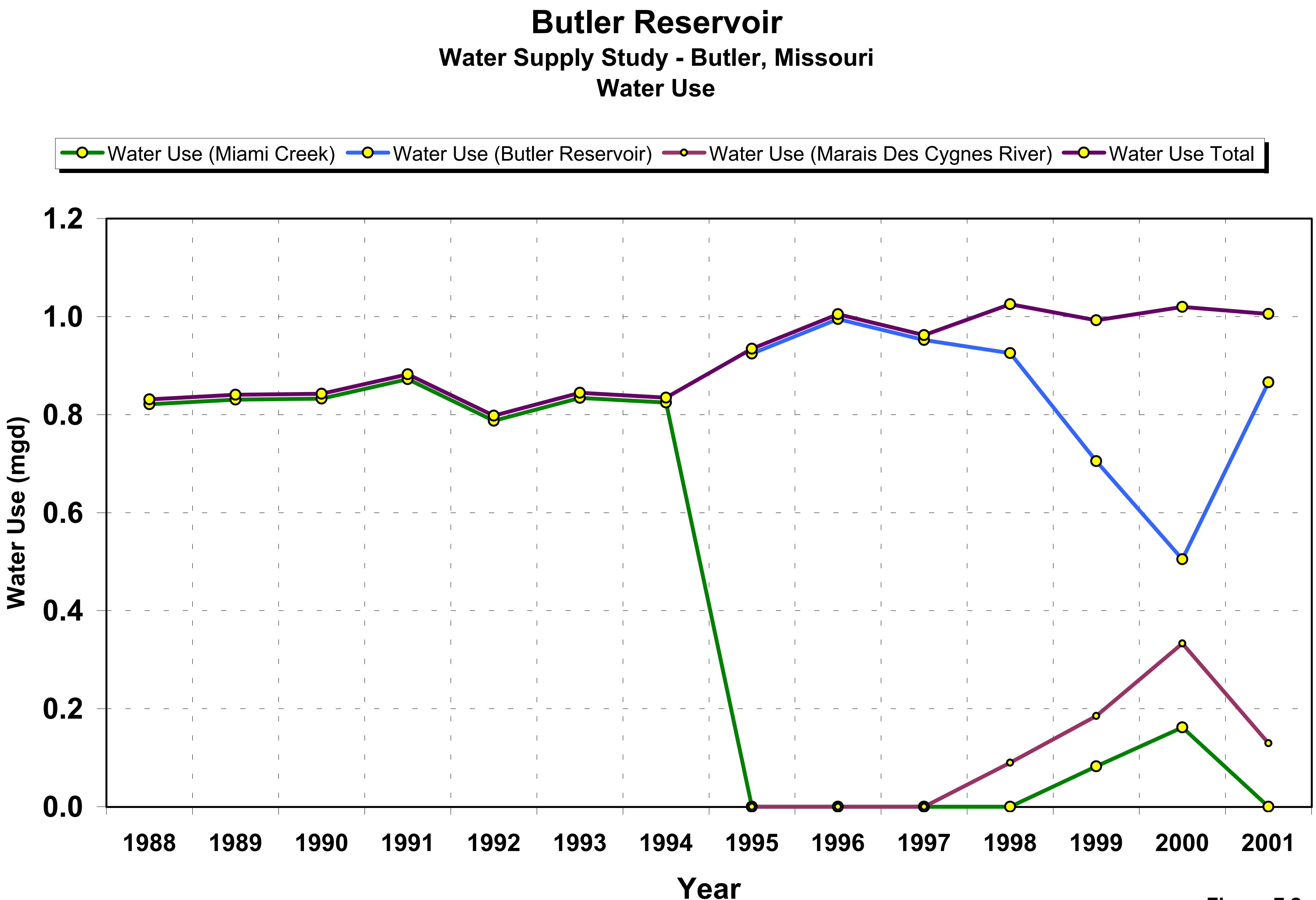

Butler Reservoir
Water Supply Study - Butler, Missouri
Water Use
Water Use (Miami Creek)
Water Use (Butler Reservoir)
Water Use (Marais Des Cygnes River)
Water Use Total
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Water Use (mgd)
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 7.2

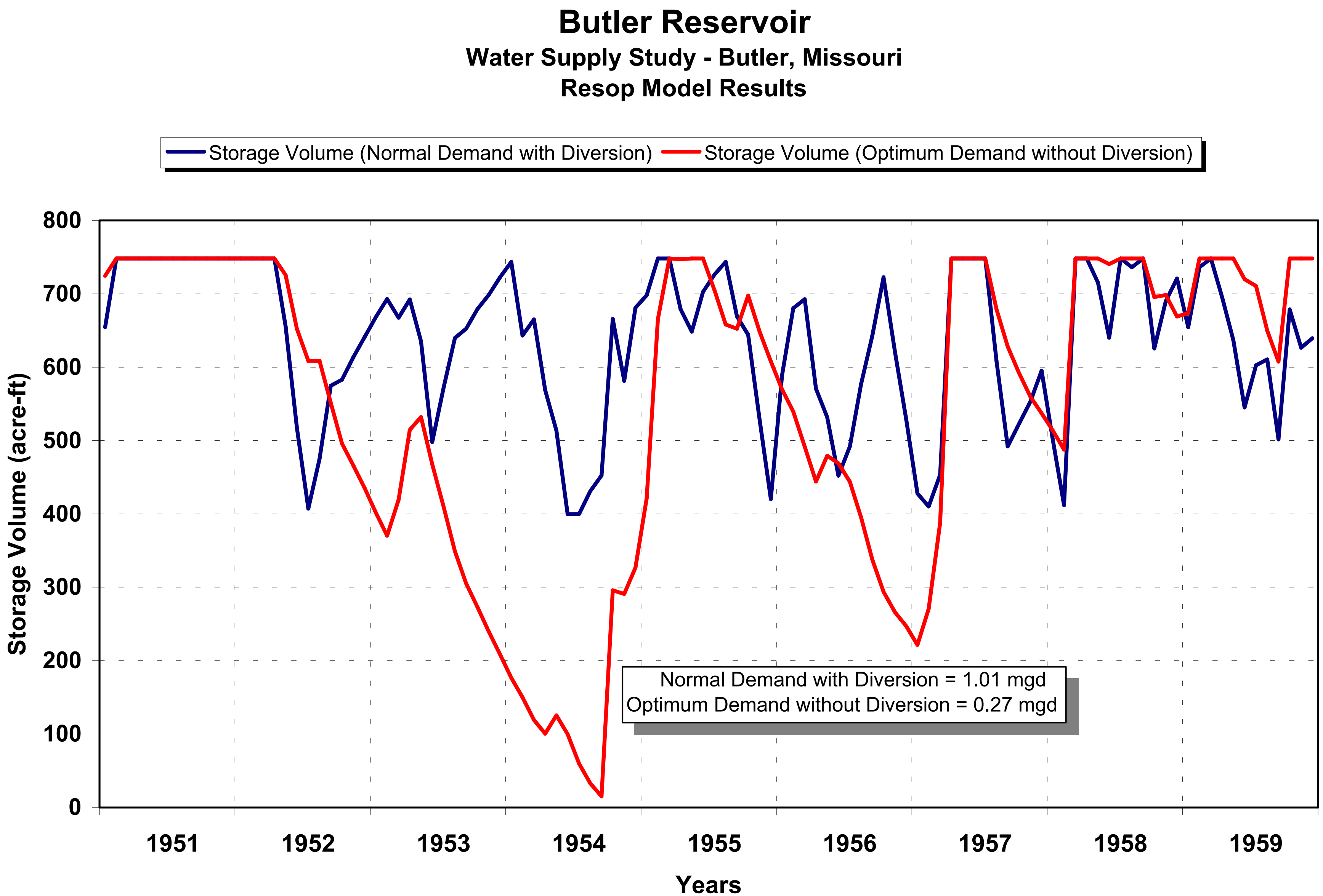

Butler Reservoir
Water Supply Study - Butler, Missouri
Resop Model Results
Storage Volume (Normal Demand with Diversion)
Storage Volume (Optimum Demand without Diversion)
Normal Demand with Diversion = 1.01 mgd
Optimum Demand without Diversion = 0.27 mgd
Storage Volume (acre-ft)
0
100
200
300
400
500
600
700
800
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 7.3

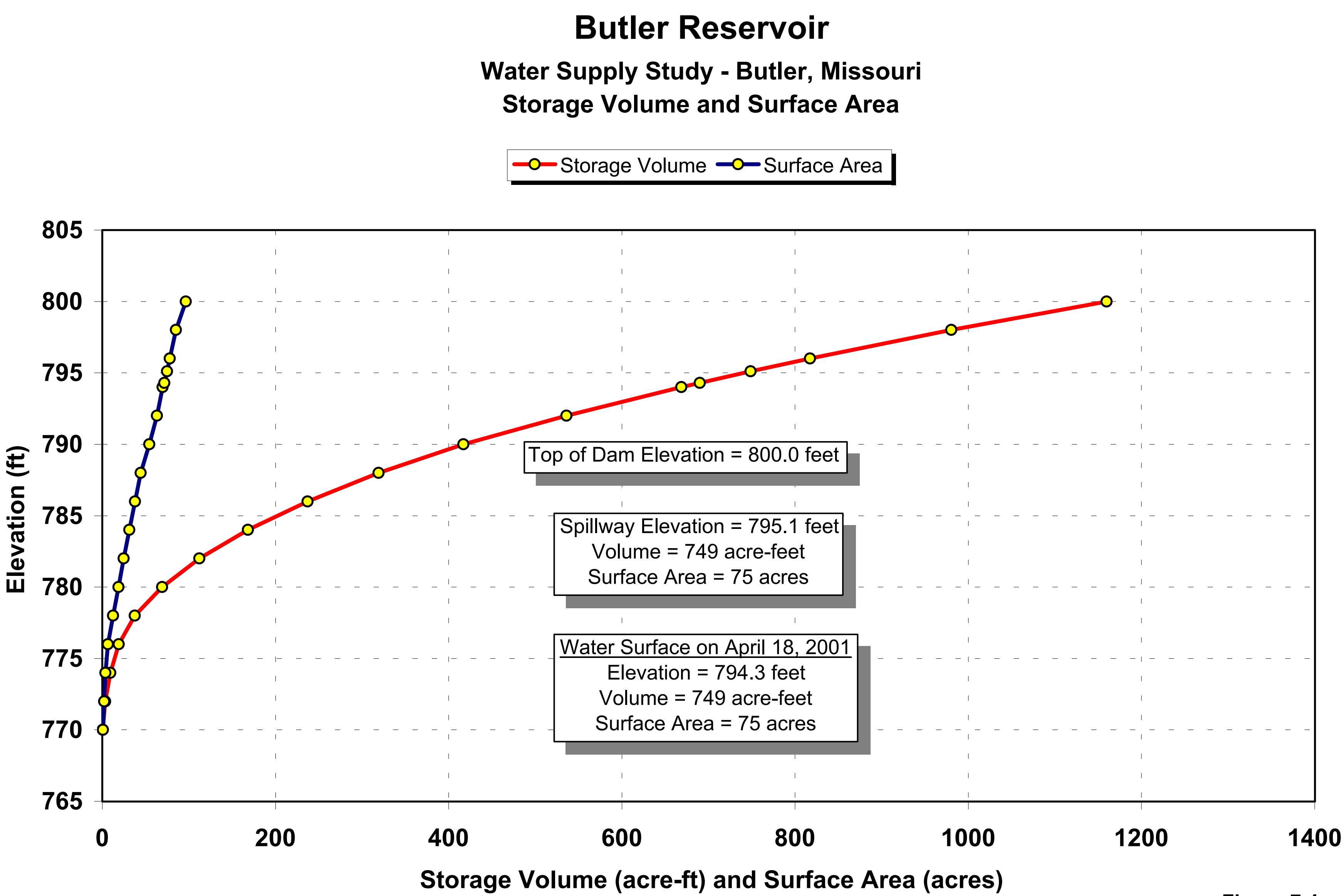

Butler Reservoir
Water Supply Study - Butler, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
805
800
795
790
785
780
775
770
765
Elevation (ft)
0
200
400
600
800
1000
1200
1400
Storage Volume (acre-ft) and Surface Area (acres)
Top of Dam Elevation = 800.0 feet
Spillway Elevation = 795.1 feet
Volume = 749 acre-feet
Surface Area = 75 acres
Water Surface on April 18, 2001
Elevation = 794.3 feet
Volume = 749 acre-feet
Surface Area = 75 acres

Figure 7.4

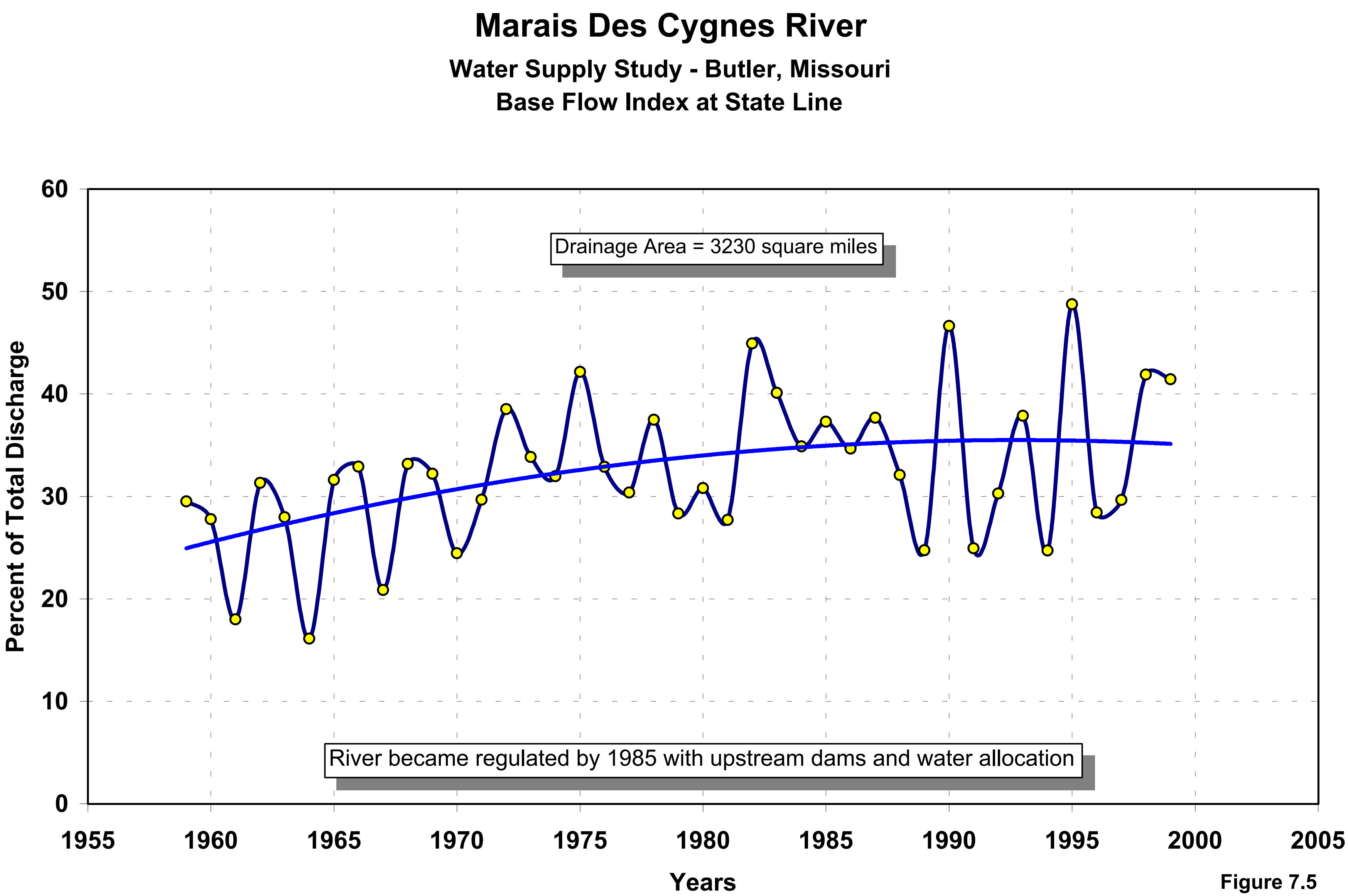

Marais Des Cygnes River
Water Supply Study - Butler, Missouri
Base Flow Index at State Line
Drainage Area = 3230 square miles
River became regulated by 1985 with upstream dams and water allocation
Percent of Total Discharge
0
10
20
30
40
50
60
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Years

Figure 7.5

Butler Reservoir
Water Supply Study - Butler, Missouri
Percent of Marias Des Cygnes River flow diverted to Butler Reservoir

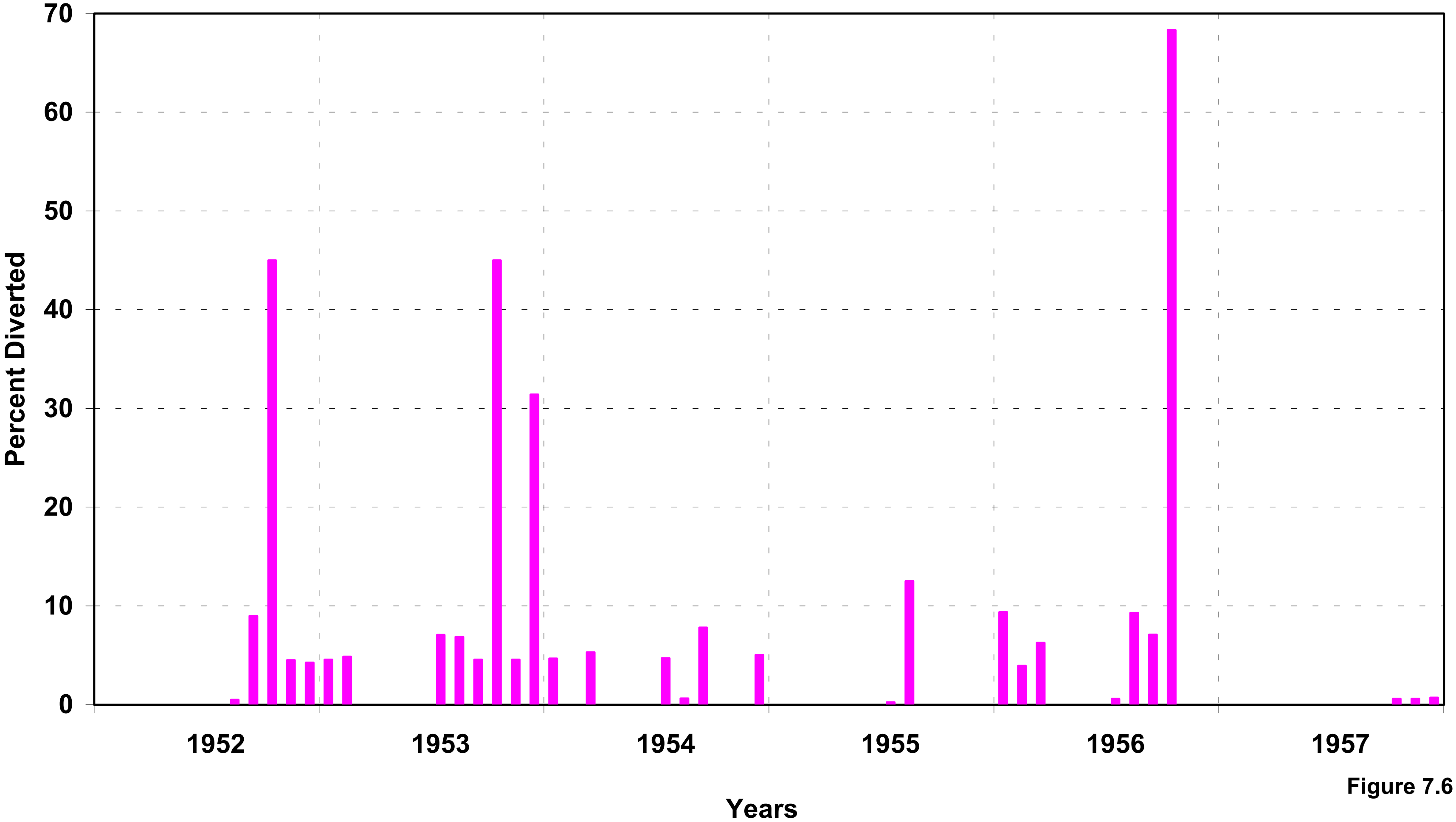


Figure 7.6

Grindstone Reservoir (GLM-A2) and Three City Lakes
Water Supply Study – Cameron, Missouri
2013 Drought Assessment Analysis

Purpose

The City of Cameron, located in the northeast corner of Clinton County in northwest Missouri, submitted a request to the Missouri Department of Natural Resources to re-evaluate the city's water supply system. Northwest Missouri is highly susceptible to drought and the city has faced multiple water shortages during the last two decades. The system was originally evaluated by the department in 2003 as part of the "*Missouri Water Supply Study*". Since then, the report has been periodically updated to reflect changes in water supply demand. This study looks at not only demand but also changes in reservoir capacity due to sedimentation. The results of this study will be used by the city to evaluate the need for and size of an additional water supply source.

I. Overview

The city's water supply system includes Reservoir #1,#2,#3, and Grindstone (GLM-A2). Reservoir #1 and #2 are located upstream of Reservoir #3 (Figure 8.1). The upstream reservoirs were built in the first half of the 20^{th} century for water supply, but now serve primarily as sediment control structures for Reservoir #3. Reservoir #1 has 103 acre-feet of storage while Reservoir #2 has 320 acre-feet of storage. Reservoir #3 was constructed in 1961 and has 938 acre-feet of storage. Water is pumped from Reservoir #3 to the water treatment plant. Combined, the three reservoirs do not have the capacity to meet the water supply demands of the city. A fourth source of water, Grindstone Reservoir, was added to the system in 1992. At the time of construction, a consulting engineering firm determined the water supply need from Grindstone to be 0.75 million gallons per day (mgd). The average daily demand increased throughout the 1990s and in 2005 the optimum demand from Grindstone was increased to 0.96 mgd by raising the elevation of the principle spillway.

Grindstone Reservoir is part of a comprehensive watershed plan for Grindstone-Lost-Muddy Creek watershed. The reservoir was constructed in cooperation between Cameron and the United States Department of Agriculture's Natural Resource Conservation Service (NRCS) through the small watershed program (PL-566). Grindstone Reservoir was designed with 569 acre-feet of sediment storage and 1,300 acre-feet of municipal water supply. In 2005 the principle spillway was raised three feet, increasing the design municipal water supply storage to 1,850 acre-feet. In addition to municipal water supply, Grindstone Reservoir also provides floodwater retardation. A 2,000 gallon-per-minute pump transfers water from Grindstone to Reservoir #3 for treatment. Pumping rates from Grindstone vary and are based on the amount of available freeboard in Reservoir #3.

The city's municipal water supply system serves the citizens of Cameron, Clinton PWSD #3, Caldwell PWSD #2, and two state correctional centers. Since 1998 average raw water use demand has averaged between 1.4 and 1.6 mgd (Figure 8.2). Between 2005 and 2012 the water treatment plant reported having maximum daily demands from 1.8 to 2.1 mgd. The system was evaluated given a demand of 1.5 mgd. It was determined that the city's water supply system does not have the ability to sustain the drought of record, which occurred in the 1950s.

Year	Annual Raw Water Use million gallons	Raw Water Average Demand mgd	Raw Water Max Demand mgd
2005	541.40	1.48	2.04
2006	537.63	1.47	2.05
2007	567.45	1.55	2.11
2008	533.04	1.46	1.83
2009	516.74	1.41	2.11
2010	511.74	1.40	1.82

2011	514.54	1.41	1.85
2012	520.92	1.43	2.07

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the NRCS of the United States Department of Agriculture. The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Refer to Appendix A for a more thorough description of the RESOP model program

II. Reservoir Capacity

In addition to reviewing current water use demands, the city also requested a bathymetric survey of each reservoir to confirm municipal water supply storage capacity. A bathymetric survey of each reservoir was completed in July 2013 by the U.S. Geological Survey (Figures 8.3.a-d). The survey was conducted using a high-resolution multibeam mapping system (MBMS) and the data was processed with CARIS HIPS and SIPS software. The maximum vertical extent of each survey was the elevation of the water surface on the date of the survey. If the elevation of the water surface on the date of the survey was below the elevation of the weir, the volume and surface area for the reservoir were extrapolated from aerial Light Detection and Ranging (LiDAR) collected in 2010 as part of the Upper Grand River LiDAR Project.

Due to the natural geomorphic processes of erosion, sediment transport, and deposition, reservoir water storage capacity will decrease with time. The rate of sedimentation in a reservoir is dependent on the characteristics of the watershed and hydrologic events that take place over the life of the reservoir. Prior to the 2013 survey, volume and surface area data for Grindstone reservoir were derived from the 1991 as-built plans. Data for Reservoir #1, #2, and #3 were derived from 1996 NRCS bathymetric surveys of the three reservoirs.

For Grindstone reservoir, a yearly sedimentation rate was determined by evaluating the difference between the municipal water supply capacity of the 1991 as-builts and the 2013 survey at the elevation of the principal spillway. In 2005, the principal spillway was raised three feet to 900.1 feet, increasing the reservoir's storage capacity to 2,423 acre-feet. Currently, reservoir storage capacity at the principle spillway is 2019 acre-feet, a decrease of 404 acre-feet with an approximate sedimentation rate of 0.7percent per year. Due to the size of Reservoir #1, #2, and #3 and the errors associated with each surveying technique, it was not feasible to calculate sedimentation rates for these reservoirs.

III. Drought Assessment Summary

Reservoir #3 supplies water directly to the treatment plant. Reservoir #1 and #2 supply water to Reservoir #3 via overflow during high rainfall periods. Water is transferred from Grindstone to Reservoir #3 by pump. The system was evaluated at a demand of 1.5 mgd. The most severe part of the drought of record began in 1956 and continued into 1957.

Reservoir #1 and #2 have an optimum demand of 0.06 (Figure 8.4.a) and 0.13 mgd (Figure 8.4.b), respectively. The primary function of these reservoirs is sediment control, therefore the demand for both reservoirs was set to zero and spillage from Reservoir #1 and #2 were added to Reservoir #3. Optimum demand for Reservoir #3 alone, with only spillage from Reservoir #1 and Reservoir #2 is 0.32 mgd (Figure 8.4.c). Grindstone Reservoir has an optimum demand of 0.85 mgd (Figure 8.4.d). As sediment continues to accumulate in the municipal water supply pool, the optimum demand for the reservoir will decrease.

To reflect normal operating procedures and simplify the model, the demand on Grindstone Reservoir was determined as the volume of water needed to return Reservoir #3 to maximum storage on a monthly basis (Figure 8.4.e). Using the "pump to maximum storage" method, the water surface elevation in Grindstone Reservoir drops below the minimum storage volume in 1954 and again in 1957. In 1954, the normal demand may be met by allowing the volume of water in Reservoir #3 to drop below full capacity. In 1957, both Grindstone and Reservoir #3 are completely depleted and the normal demand cannot be

met. Optimum demand from Reservoir #3, including spillage from Reservoir #1 and #2 and monthly optimum pumping from Grindstone, is 1.18 mgd (Figure 8.4.f).

IV. RESOP Model Parameters

Terms in brackets (and bold text) refer to "control words" for the RESOP program. Each term represents one or more values used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of each reservoir completed by the U.S. Geological Survey in July 2013 and aerial LiDAR data collected as part of the Upper Grand River LiDAR Project in 2010 (Figures 8.5.a-d)

Cameron Reservoirs Physical Data

Reservoir #1			Reservoir #2		
Elevation (feet)	Area (acres)	Volume (acre-feet)	Elevation (feet)	Area (acres)	Volume (acre-feet)
926.0	0.0	0.0	918.0	0.0	0.0
928.0	0.7	0.1	920.0	1.1	1.2
930.0	6.4	7.4	922.0	2.3	4.5
932.0	9.6	23.7	924.0	4.0	10.9
934.0	12.0	45.3	926.0	5.3	20.2
936.0	14.0	71.3	928.0	7.1	32.5
937.9	16.4	99.8	930.0	9.2	48.8
938.0	16.5	101.4	932.0	12.0	70.2
938.1	16.6	103.1	934.0	14.4	96.6
			936.0	17.3	128.0
			938.0	20.9	167.0
			940.0	23.9	211.0
			942.0	28.0	263.0
			943.3	31.0	301.0
			943.9	31.8	319.6
Weir elevation = 938.1 feet			Weir elevation = 943.9 feet		

Reservoir #3			Grindstone Reservoir		
Elevation (feet)	Area (acres)	Volume (acre-feet)	Elevation (feet)	Area (acres)	Volume (acre-feet)
888.0	0.0	0.0	878.0	1.4	1.1
890.0	0.2	0.1	880.0	2.7	5.0
892.0	3.1	2.7	882.0	8.6	13.8
894.0	10.8	15.2	884.0	41.3	58.0

896.0	21.5	49.0	886.0	74.0	175.0
898.0	27.9	98.2	888.0	90.8	342.0
900.0	37.5	163.0	890.0	107.0	540.0
902.0	49.3	250.0	892.0	119.0	766.0
904.0	64.1	363.0	894.0	134.0	1020.0
906.0	75.0	503.0	896.0	155.0	1310.0
908.0	86.0	663.0	898.0	175.0	1640.0
910.0	92.4	845.0	899.8	196.0	1960.0
910.6	92.4	896.0	900.0	197.0	1999.0
911.0	93.5	938.1	900.1	197.3	2019.0
Weir elevation = 911.0 feet			Weir elevation = 900.1 feet		

[LIMITS]

Reservoir #1
Maximum storage ....103 acre-feet
Minimum storage ....8 acre-feet
Drainage basin size ....1.65 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

Reservoir #2
Maximum storage ....320 acre-feet
Minimum storage ....60 acre-feet
Drainage basin size ....1.80 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

Reservoir #3
Maximum storage ....938 acre-feet
Minimum storage ....163 acre-feet
Drainage basin size ....1.73 square miles
Total drainage basin size ....5.18 square miles

Grindstone Reservoir
Maximum storage ....2019 acre-feet
Minimum storage ....441 acre-feet
Drainage basin size ....20.91 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950s. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Grindstone Reservoir is approximately 1.1 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

Seepage from Reservoir #3 is estimated to be 1.0 inches per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible

Seepage from Reservoir #1 and #2 was considered to be 0.0 inches per month because all seepage would drain to Reservoir #3 and would not be lost to the system.

[RAINFALL]

Rainfall data was not continuous at nearby gages. As a result the Gallatin gage was used for the period 1951 through 1954 and the Hamilton gage was used from 1954 through 1959.

Average precipitation in Hamilton was 37.1 inches between 1954 and 2001. The most severe drought occurred between 1953 and 1957 with annual precipitation values in Hamilton of 21.81 inches, 37.26 inches, 28.21 inches, 21.99 inches, and 30.43 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the East Fork Big Creek stream gauge located at Bethany, Missouri, approximately 35 miles north of Cameron. The drainage area monitored by this stream gauge covers approximately 95 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Cameron, individual storm events were considered. Antecedent rainfall was estimated for each storm event and adjustments to the NRCS runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from each of Cameron's reservoirs due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard and New Franklin, Missouri depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

This analysis completed using a demand 1.5 mgd. Cameron's water treatment plant provided Missouri Department of Natural Resources Water Resources Center with water use data from 2005-2012. Data prior to 2005 was obtained from the department's "*Major Water Users Data Base*".

[OTHER]

Other is the gain or loss from sources other than the above listed control words. Grindstone Reservoir had no gains or losses to include. Reservoir #3 required releases from Reservoir #1 and #2 be added as well as the inflow pumped from Grindstone. Because of limitations of the RESOP program, as written, spillage from Reservoir #1 is included as inflow into Reservoir #2 with Reservoir #2 spilling into Reservoir #3. Due to the small size of the Reservoir #1 and #2, the error associated with this assumption is negligible. Water pumped from Grindstone is added to Reservoir #3 with the control word "Other".

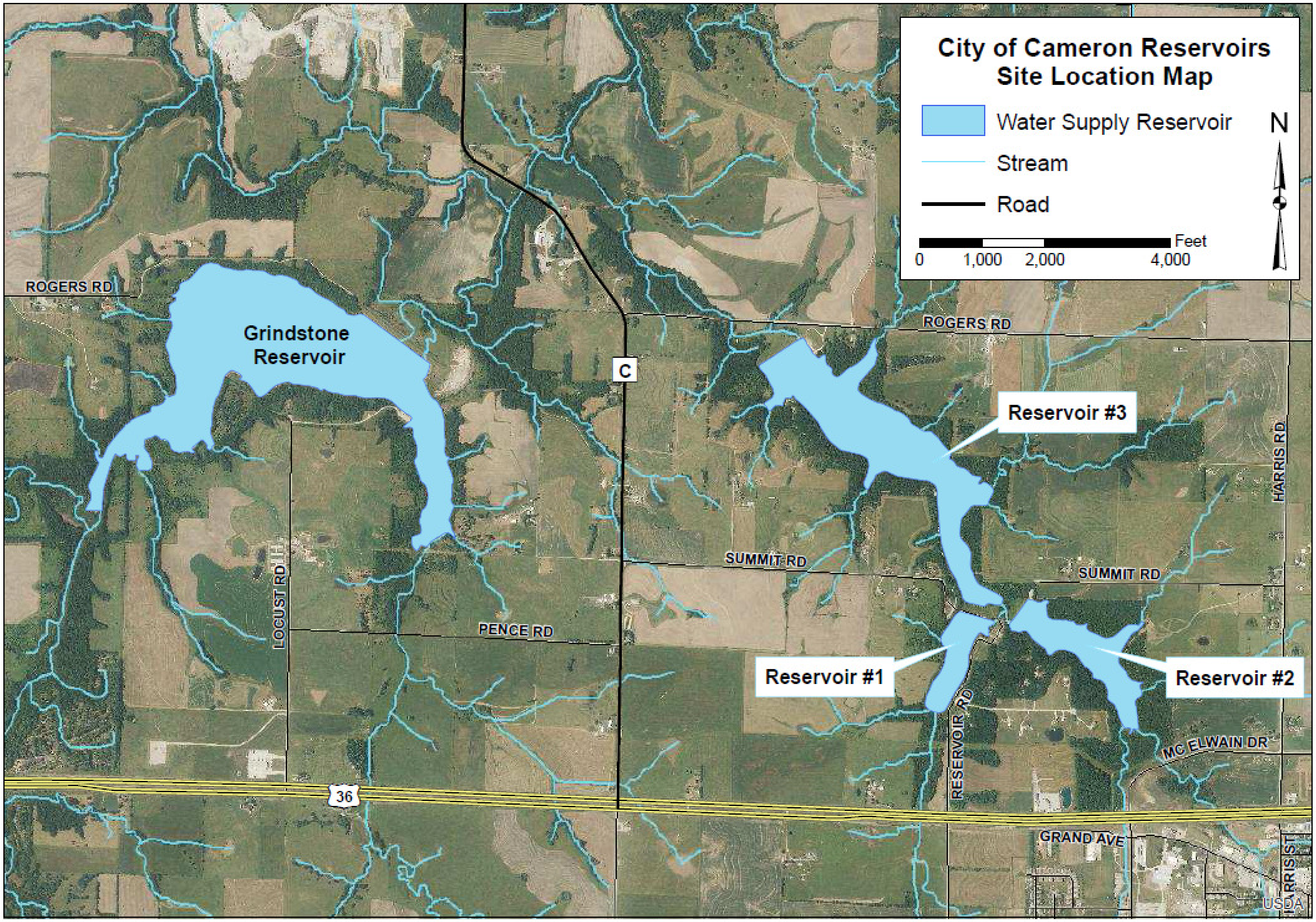

City of Cameron Reservoirs
Site Location Map
Water Supply Reservoir
Stream
Road
N
Feet
0
1,000
2,000
4,000
Grindstone Reservoir
Reservoir #3
Reservoir #1
Reservoir #2
ROGERS RD
ROGERS RD
SUMMIT RD
SUMMIT RD
PENCE RD
LOCUST RD
RESERVOIR RD
HARRIS RD
MC ELWAIN DR
GRAND AVE
C
36
USDA

Figure 8.1

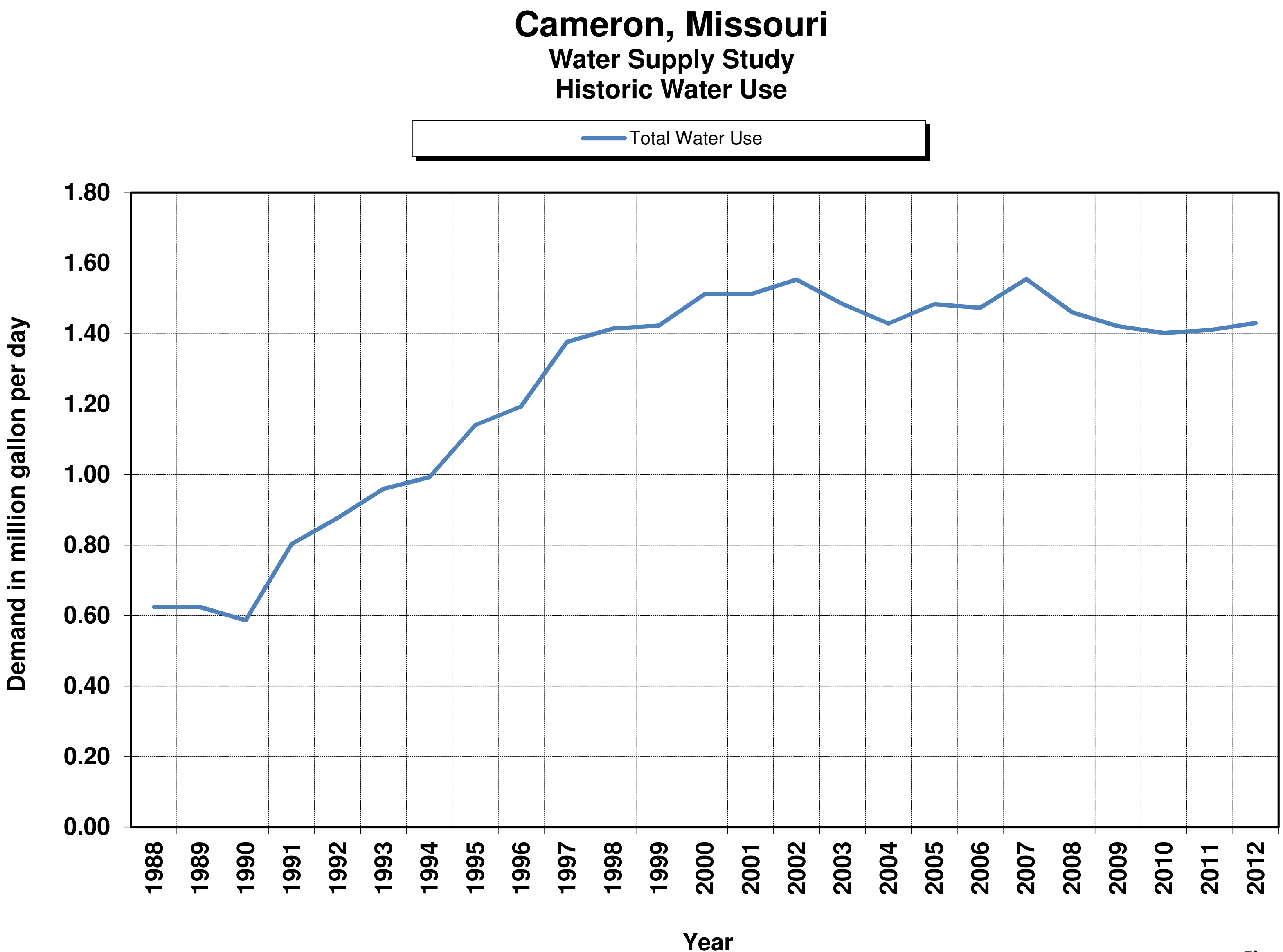
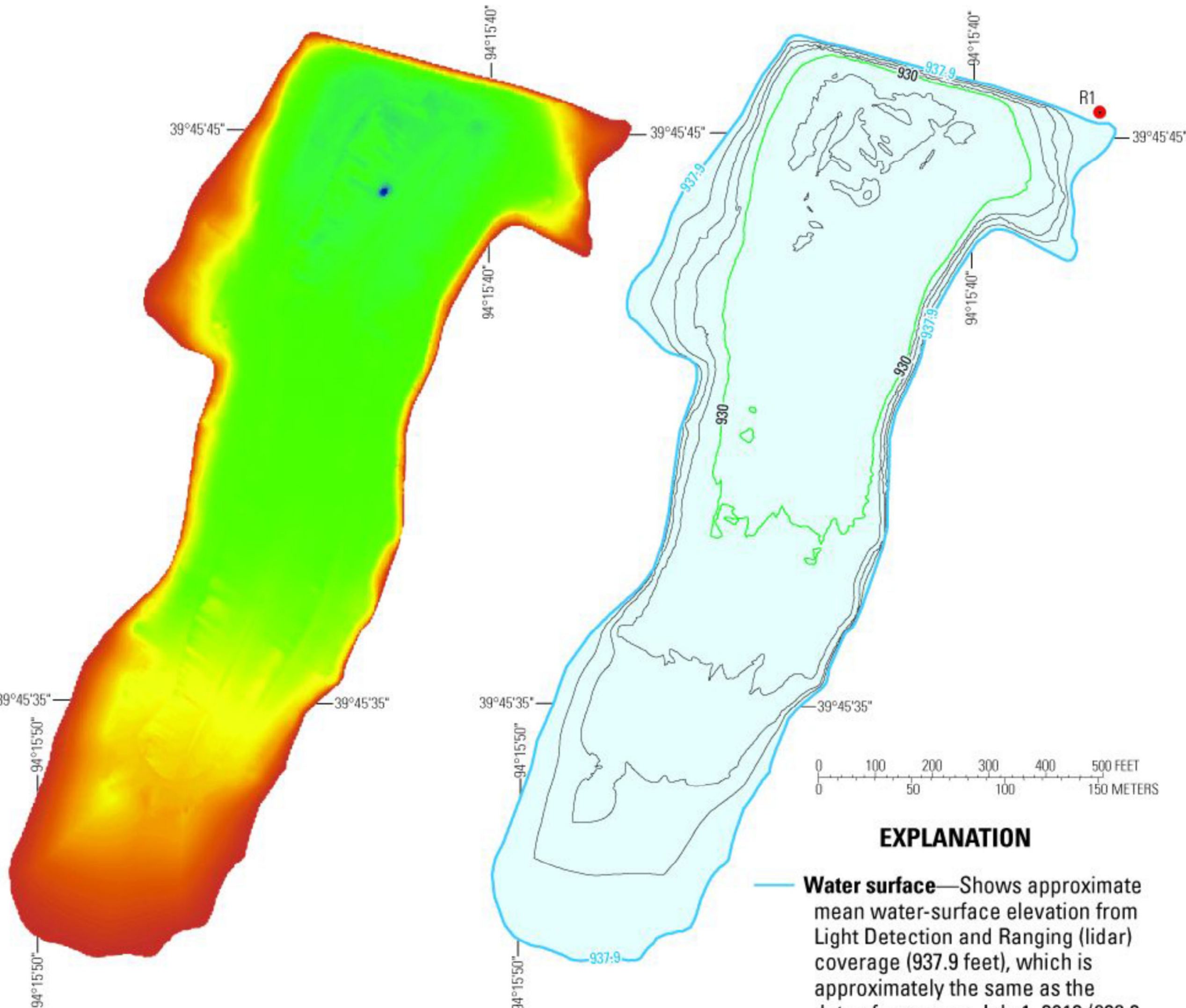

Cameron, Missouri
Water Supply Study
Historic Water Use
Total Water Use
Demand in million gallon per day
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

Figure 8.2



Bathymetric index contour, 930 feet—Shows elevation of lake bottom. Elevation referenced to North American Vertical Datum of 1988.

Bathymetric contour—Shows elevation of lake bottom. Contour interval 2 feet. Elevations referenced to North American Vertical Datum of 1988.

R1 U.S. Geological Survey reference marker and identifier—R1 is a chiseled square on southwest end of northwest spillway wall; elevation 947.72 feet.

EXPLANATION

Elevation of the lake bottom, in feet above North American Vertical Datum of 1988.

937.9
936.0
934.0
932.0
930.0
928.0
926.0
924.3

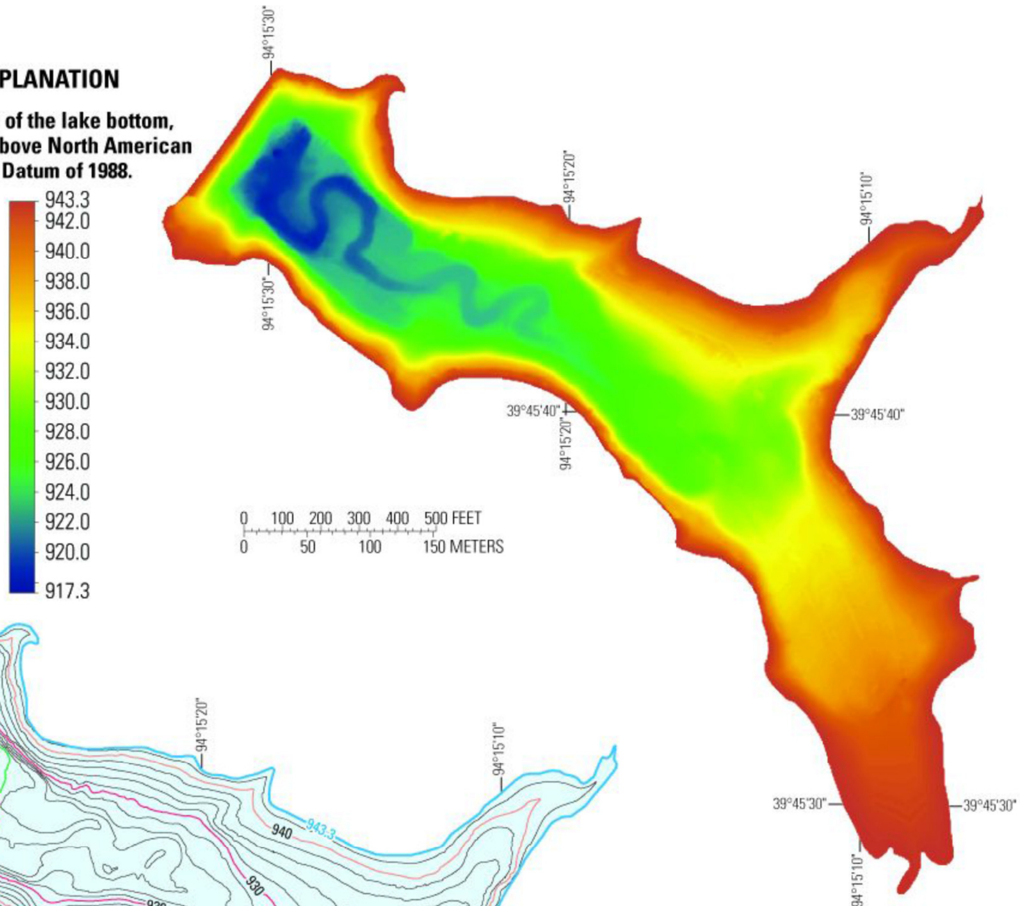
Missouri, on July 2, 2013.
[The average water-surface elevation during the survey was 938.3 feet above the North American Vertical Datum of 1988; volumes calculated from bathymetric surface with mean total propagated uncertainty of 0.49 feet]

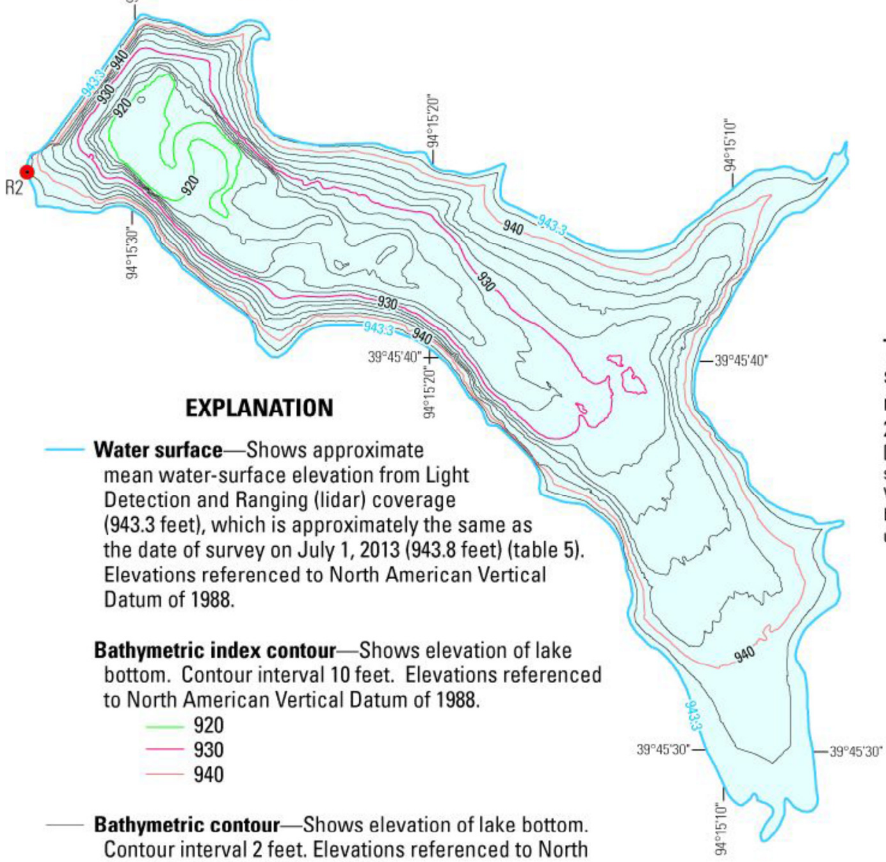
Elevation, in feet	Area, in acres	Capacity, in acre-feet
926.0	0.00	0.00
928.0	0.65	0.10
930.0	6.40	7.44
932.0	9.55	23.7
934.0	12.0	45.3
936.0	14.0	71.3
937.9	16.4	99.8

Figure 8.3.a

EXPLANATION

Elevation of the lake bottom, in feet above North American Vertical Datum of 1988.





EXPLANATION

Water surface—Shows approximate mean water-surface elevation from Light Detection and Ranging (lidar) coverage (943.3 feet), which is approximately the same as the date of survey on July 1, 2013 (943.8 feet) (table 5). Elevations referenced to North American Vertical Datum of 1988.

Bathymetric index contour—Shows elevation of lake bottom. Contour interval 10 feet. Elevations referenced to North American Vertical Datum of 1988.
- 920
- 930
- 940

Bathymetric contour—Shows elevation of lake bottom. Contour interval 2 feet. Elevations referenced to North American Vertical Datum of 1988.

R2 **U.S. Geological Survey reference marker and identifier**—R2 is a chiseled arrow near the middle of the southwest spillway wall; elevation 948.20 feet.

Table 5. Area and capacity at specified elevations for Reservoir 2 near Cameron, Missouri, on July 1, 2013.

[The average water-surface elevation during the survey was 943.8 feet above the North American Vertical Datum of 1988; volumes calculated from bathymetric surface with mean total propagated uncertainty of 0.51 feet]

Elevation, in feet	Area, in acres	Capacity, in acre-feet
918.0	0.01	0.00
920.0	1.14	1.15
922.0	2.32	4.50
924.0	3.99	10.9
926.0	5.33	20.2
928.0	7.10	32.5
930.0	9.22	48.8
932.0	12.0	70.2
934.0	14.4	96.6
936.0	17.3	128
938.0	20.9	167
940.0	23.9	211
942.0	28.0	263
943.3	31.0	301

Figure 8.3.b

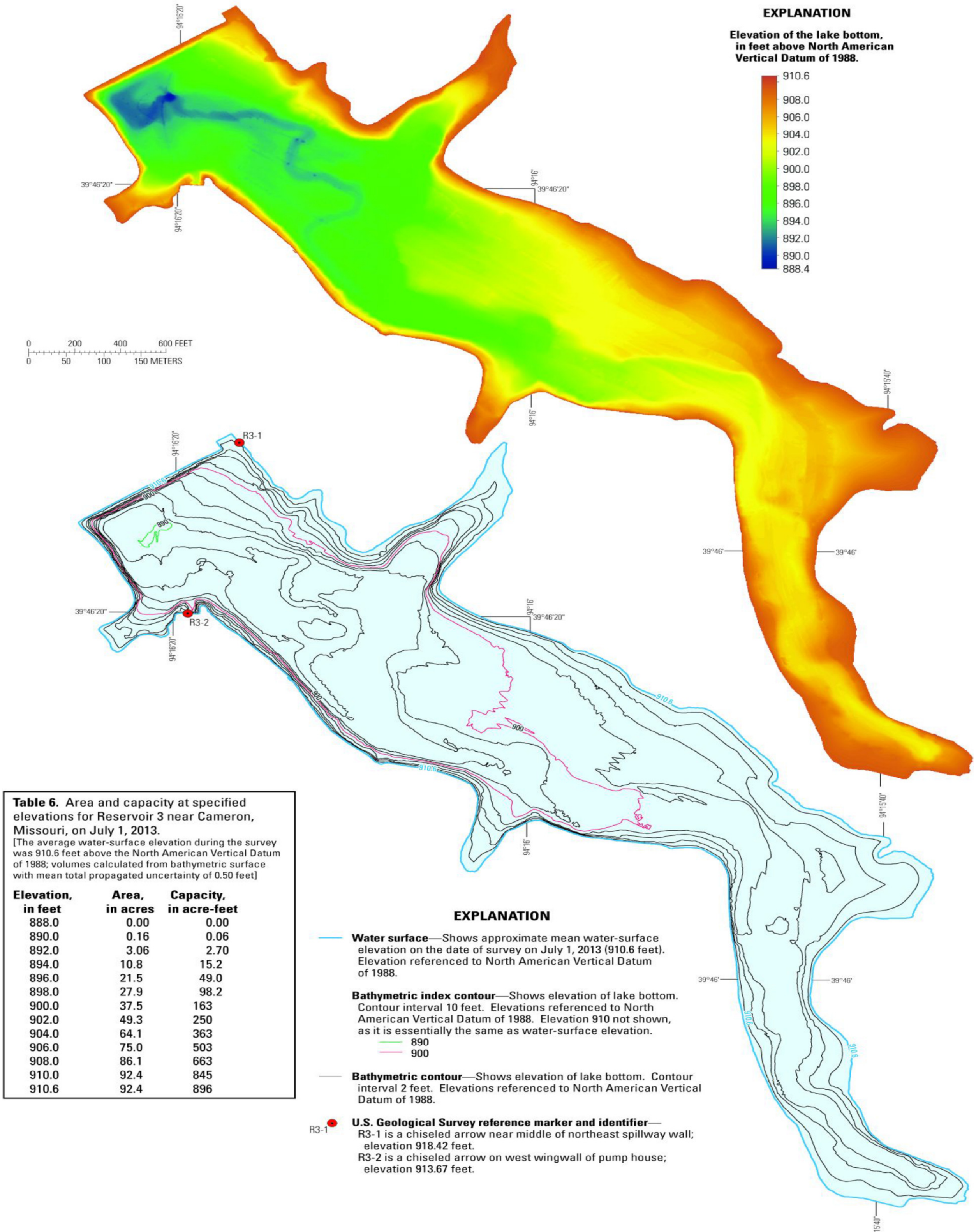
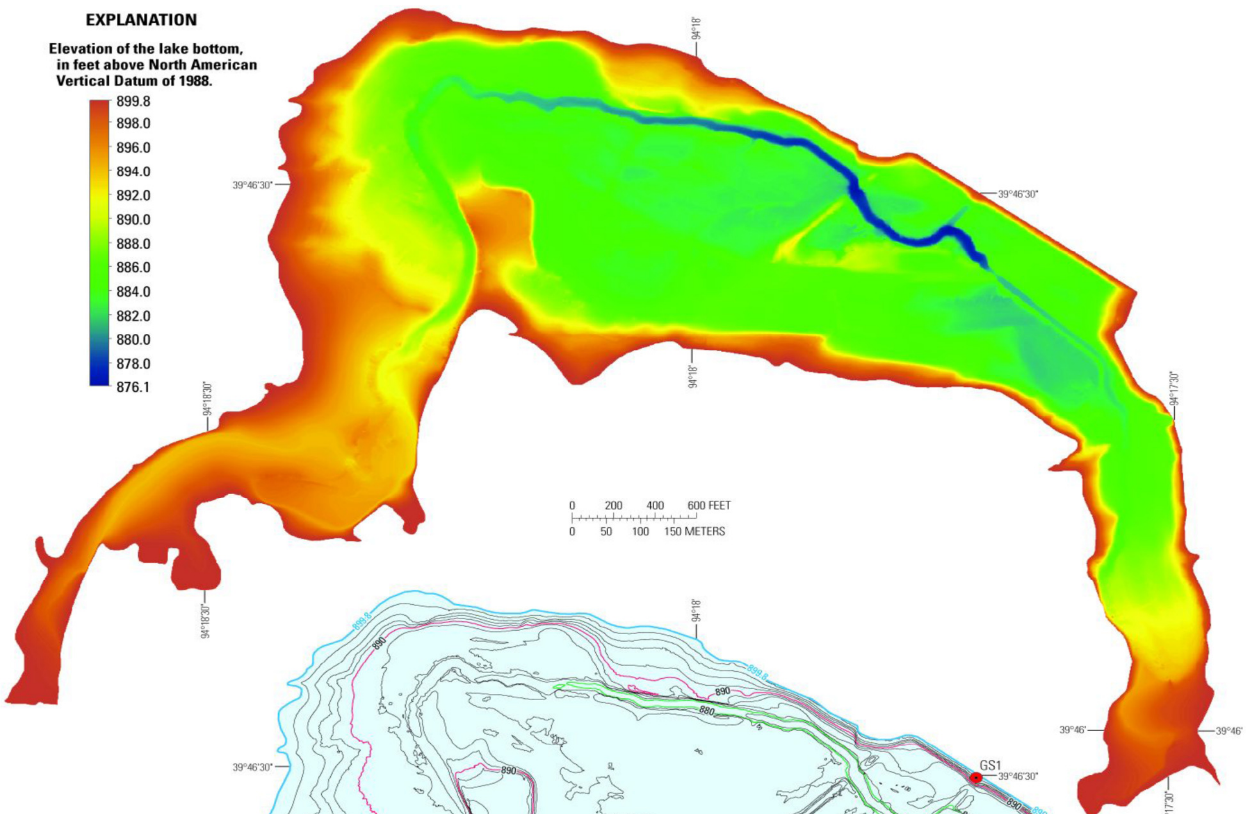


Table 6. Area and capacity at specified elevations for Reservoir 3 near Cameron, Missouri, on July 1, 2013.
[The average water-surface elevation during the survey was 910.6 feet above the North American Vertical Datum of 1988; volumes calculated from bathymetric surface with mean total propagated uncertainty of 0.50 feet]

Elevation, in feet	Area, in acres	Capacity, in acre-feet
888.0	0.00	0.00
890.0	0.16	0.06
892.0	3.06	2.70
894.0	10.8	15.2
896.0	21.5	49.0
898.0	27.9	98.2
900.0	37.5	163
902.0	49.3	250
904.0	64.1	363
906.0	75.0	503
908.0	86.1	663
910.0	92.4	845
910.6	92.4	896

Figure 8.3.c



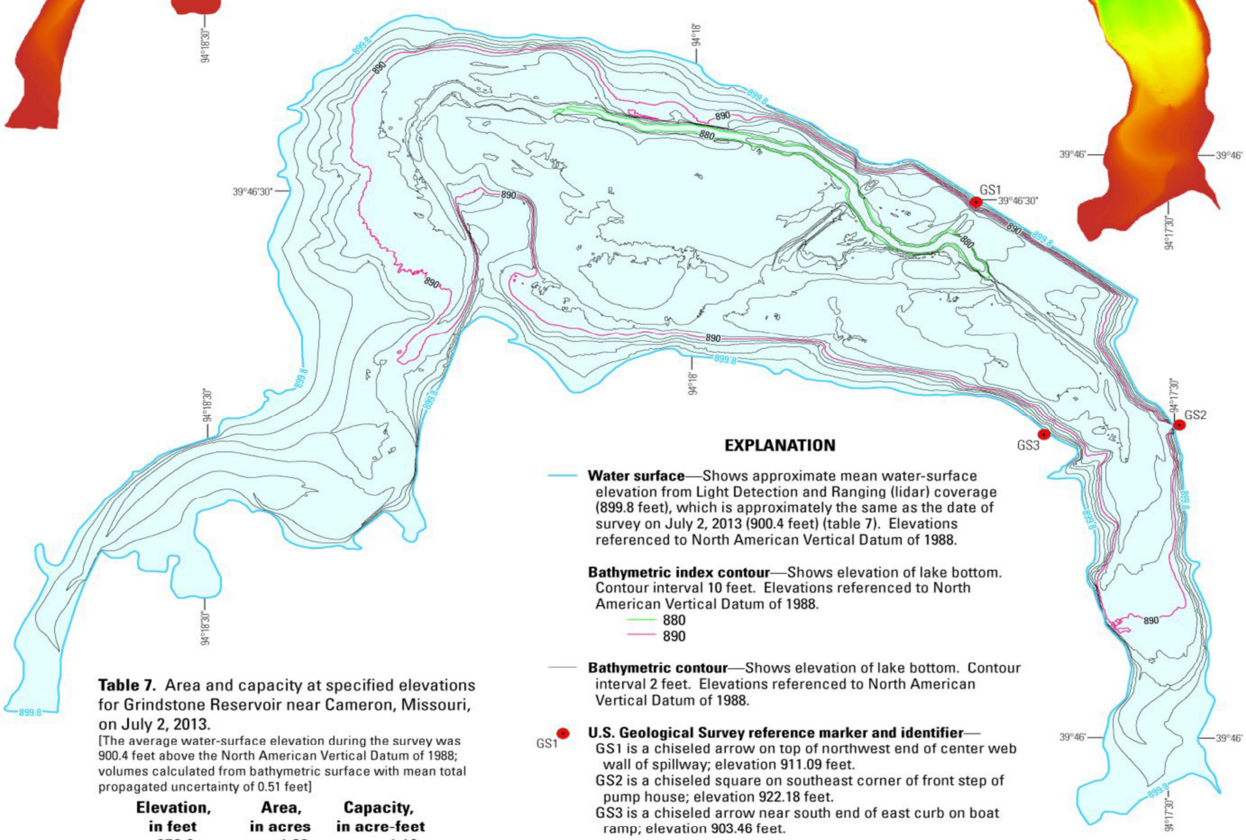


Table 7. Area and capacity at specified elevations for Grindstone Reservoir near Cameron, Missouri, on July 2, 2013.

[The average water-surface elevation during the survey was 900.4 feet above the North American Vertical Datum of 1988; volumes calculated from bathymetric surface with mean total propagated uncertainty of 0.51 feet]

Elevation, in feet	Area, in acres	Capacity, in acre-feet
878.0	1.38	1.10
880.0	2.66	5.01
882.0	8.61	13.8
884.0	41.3	58.0
886.0	74.0	175
888.0	90.8	342
890.0	107	540
892.0	119	766
894.0	134	1,020
896.0	155	1,310
898.0	175	1,640
899.8	196	1,960

Figure 8.3.d

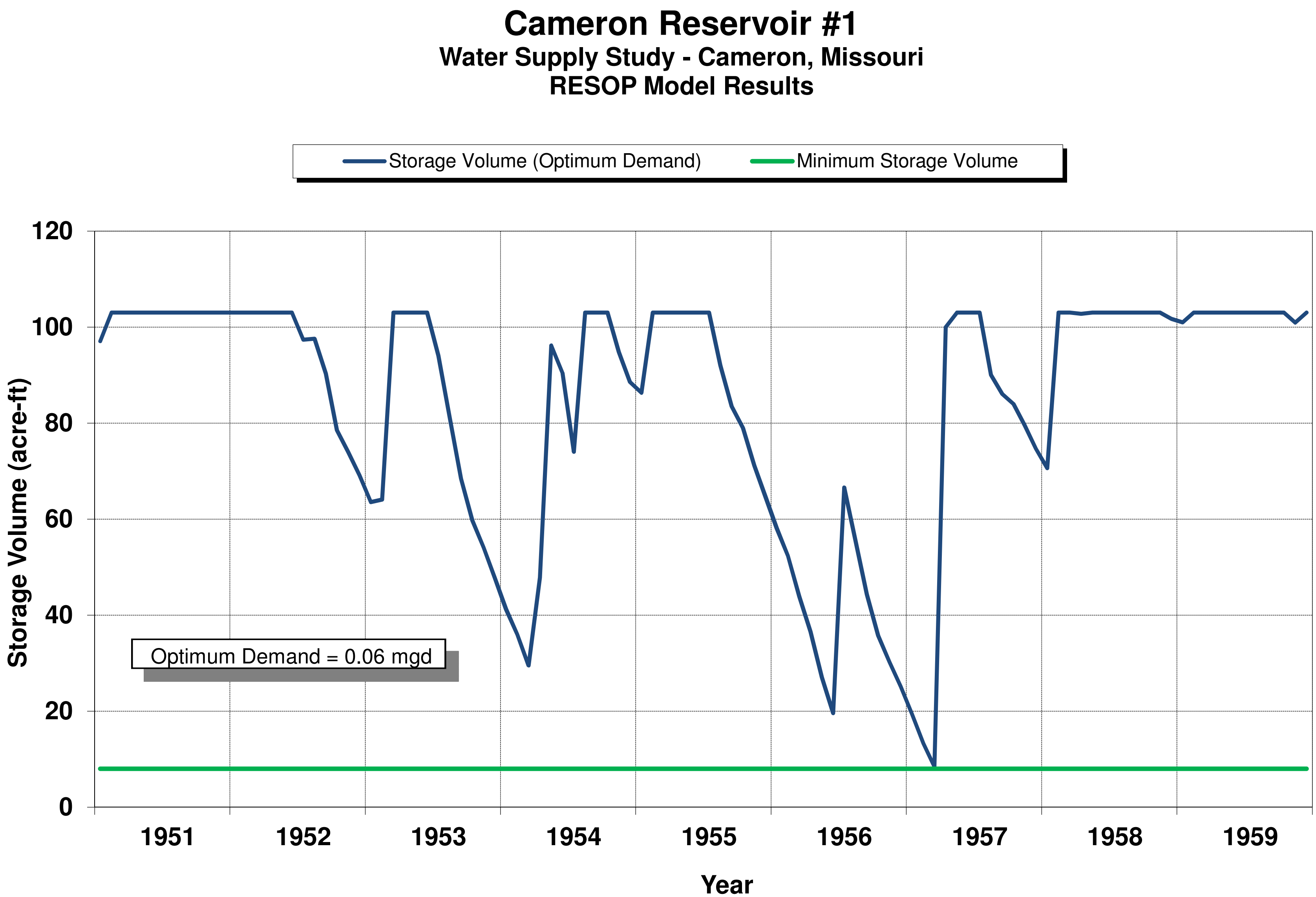

Cameron Reservoir #1
Water Supply Study - Cameron, Missouri
RESOP Model Results
Storage Volume (Optimum Demand)
Minimum Storage Volume
Optimum Demand = 0.06 mgd
Storage Volume (acre-ft)
120
100
80
60
40
20
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 8.4.a

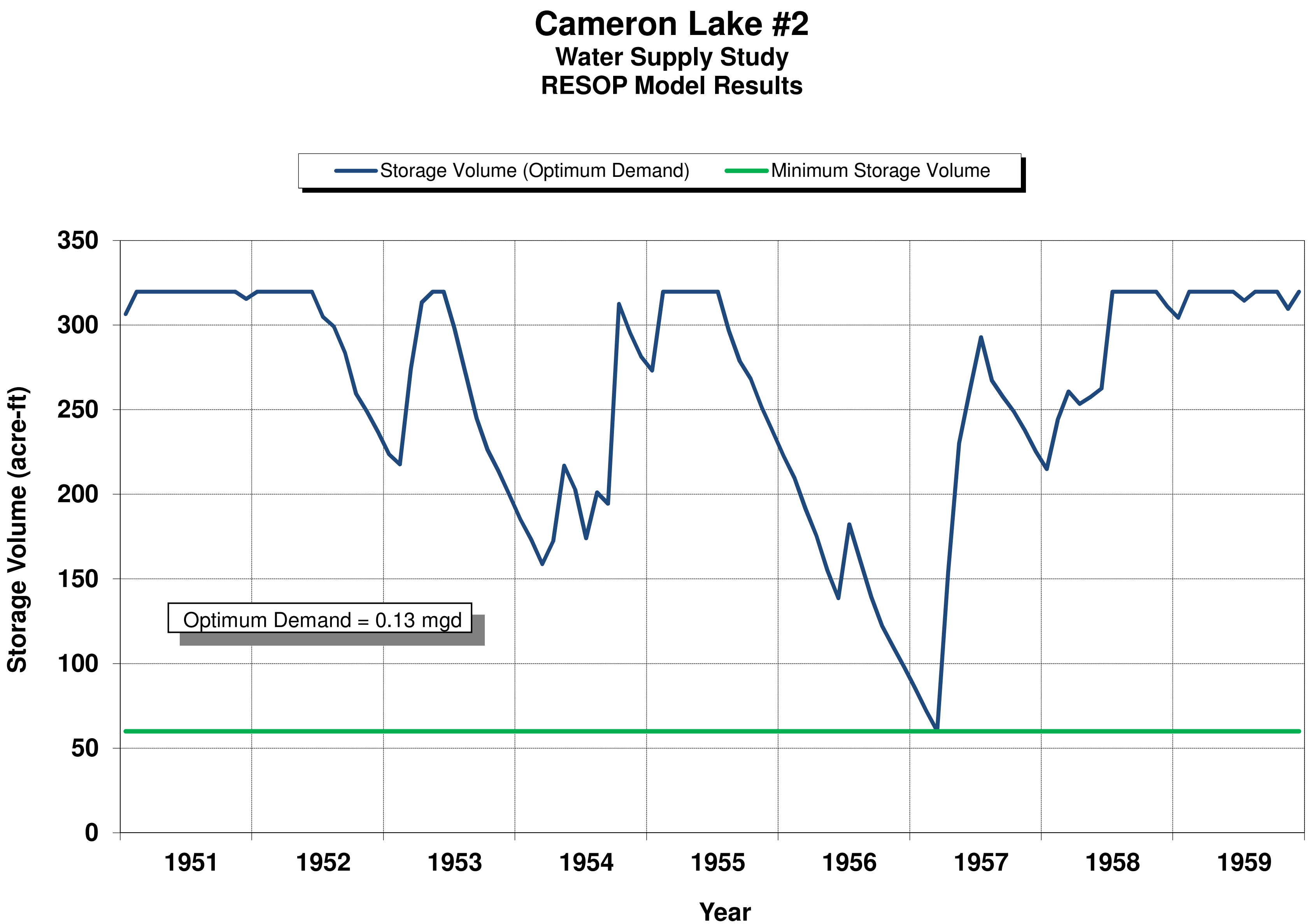

Cameron Lake #2
Water Supply Study
RESOP Model Results
Storage Volume (Optimum Demand)
Minimum Storage Volume
Storage Volume (acre-ft)
350
300
250
200
150
100
50
0
Optimum Demand = 0.13 mgd
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 8.4.b

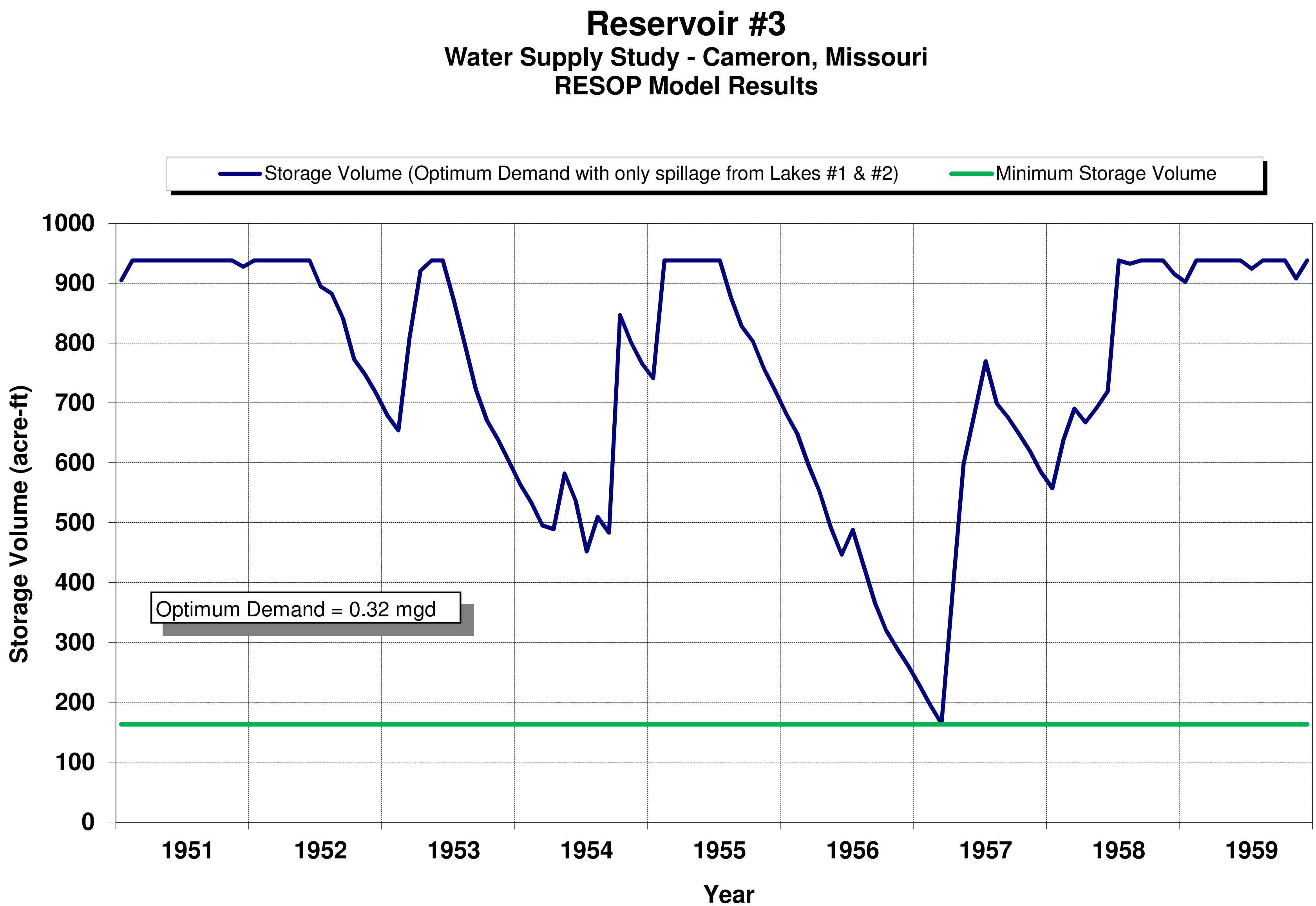

Reservoir #3
Water Supply Study - Cameron, Missouri
RESOP Model Results
Storage Volume (Optimum Demand with only spillage from Lakes #1 & #2)
Minimum Storage Volume
Optimum Demand = 0.32 mgd
Storage Volume (acre-ft)
1000
900
800
700
600
500
400
300
200
100
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 8.4.c

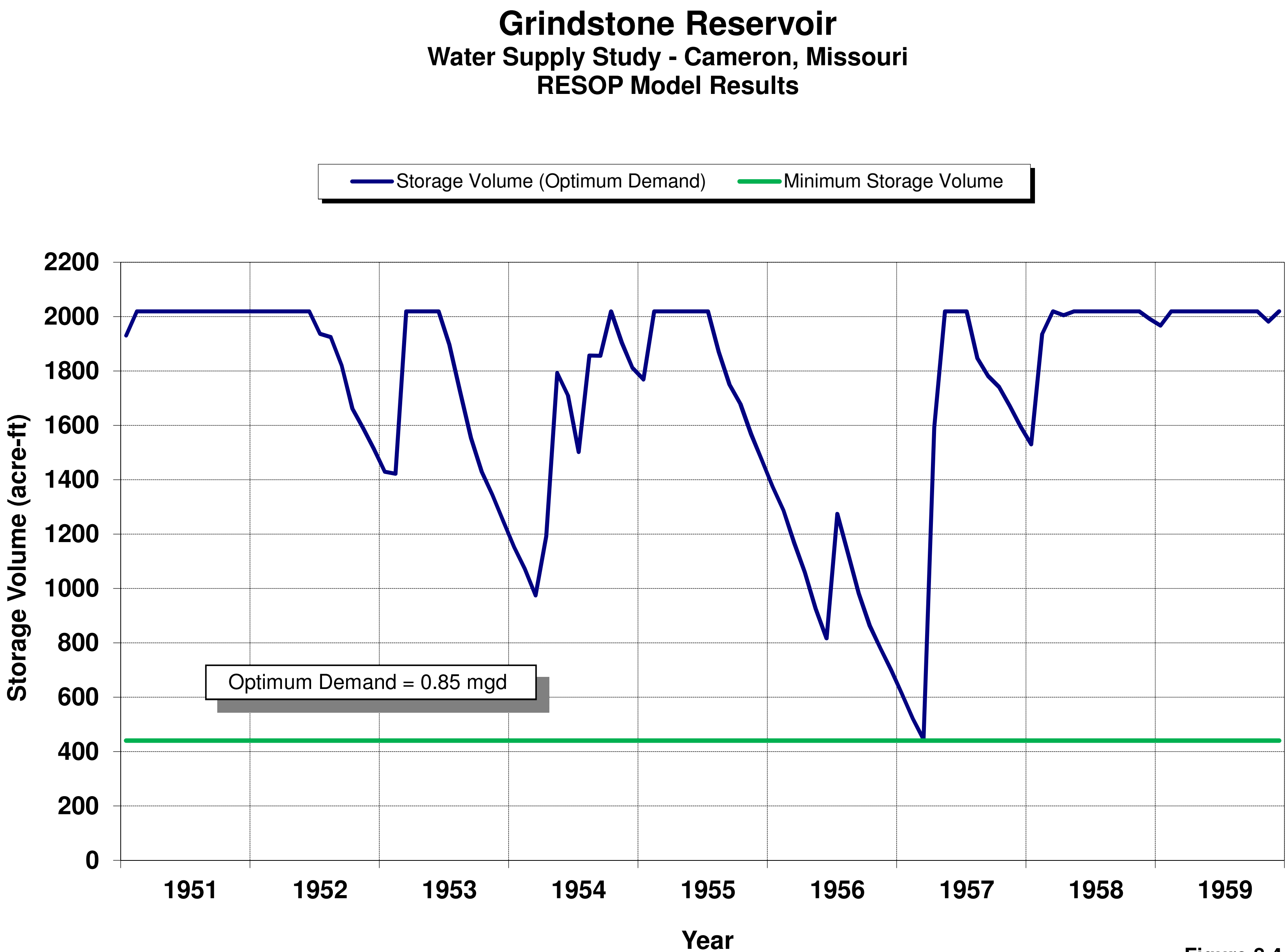

Grindstone Reservoir
Water Supply Study - Cameron, Missouri
RESOP Model Results
Storage Volume (Optimum Demand)
Minimum Storage Volume
Storage Volume (acre-ft)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Optimum Demand = 0.85 mgd
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 8.4.d

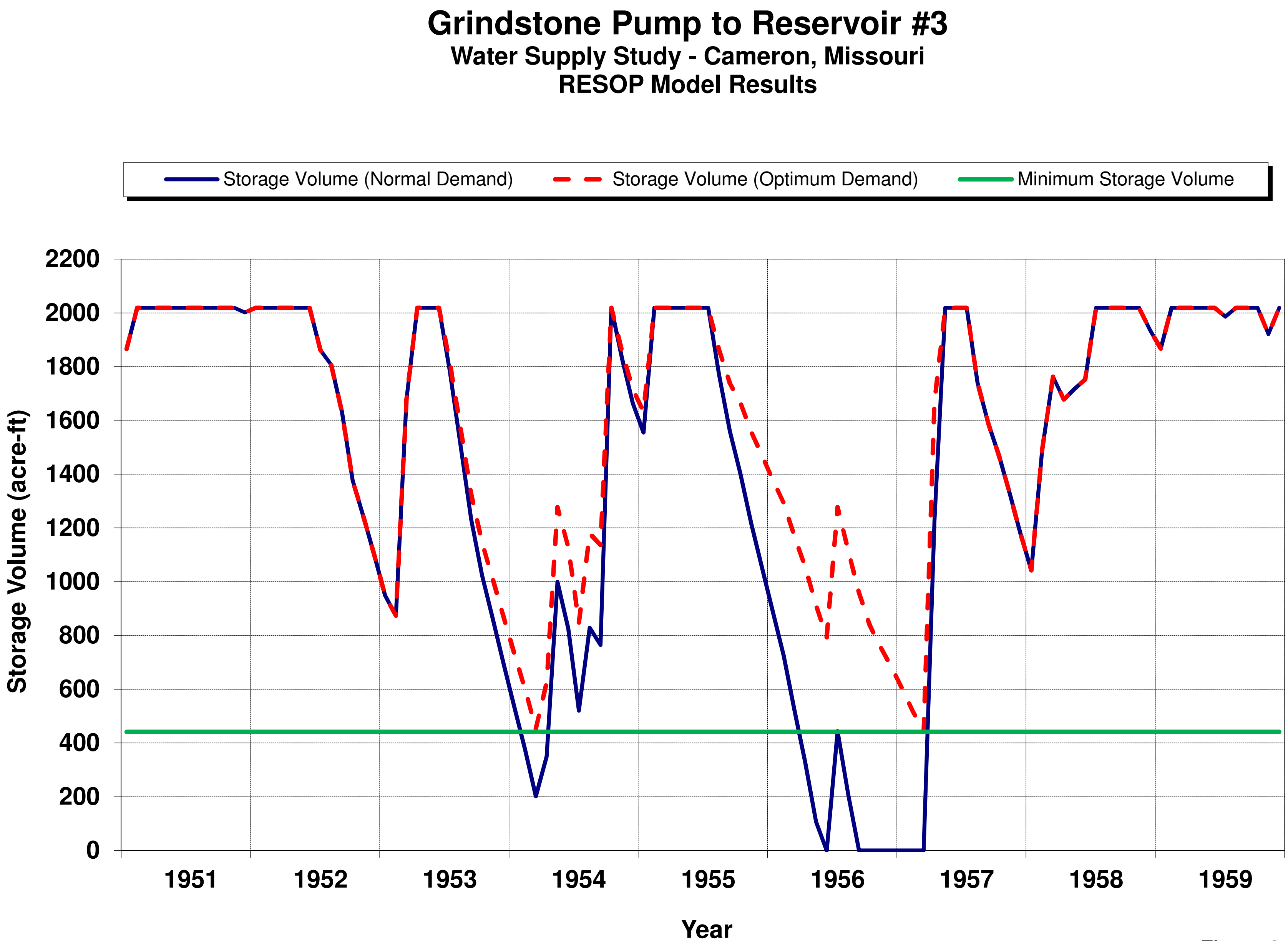

Grindstone Pump to Reservoir #3
Water Supply Study - Cameron, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Minimum Storage Volume
Storage Volume (acre-ft)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 8.4.e

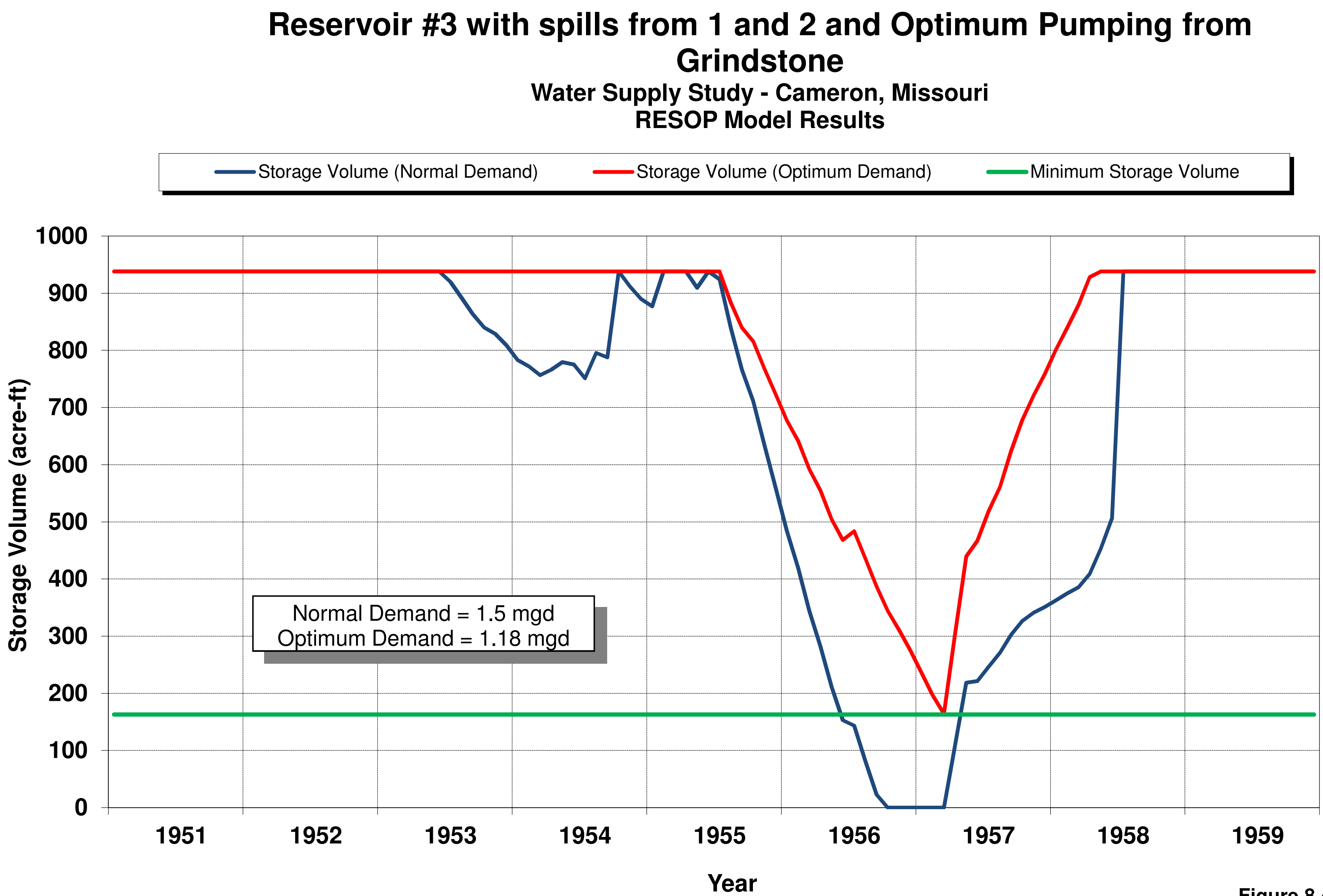

Reservoir #3 with spills from 1 and 2 and Optimum Pumping from Grindstone
Water Supply Study - Cameron, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Minimum Storage Volume
Normal Demand = 1.5 mgd
Optimum Demand = 1.18 mgd
Storage Volume (acre-ft)
1000
900
800
700
600
500
400
300
200
100
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 8.4.f

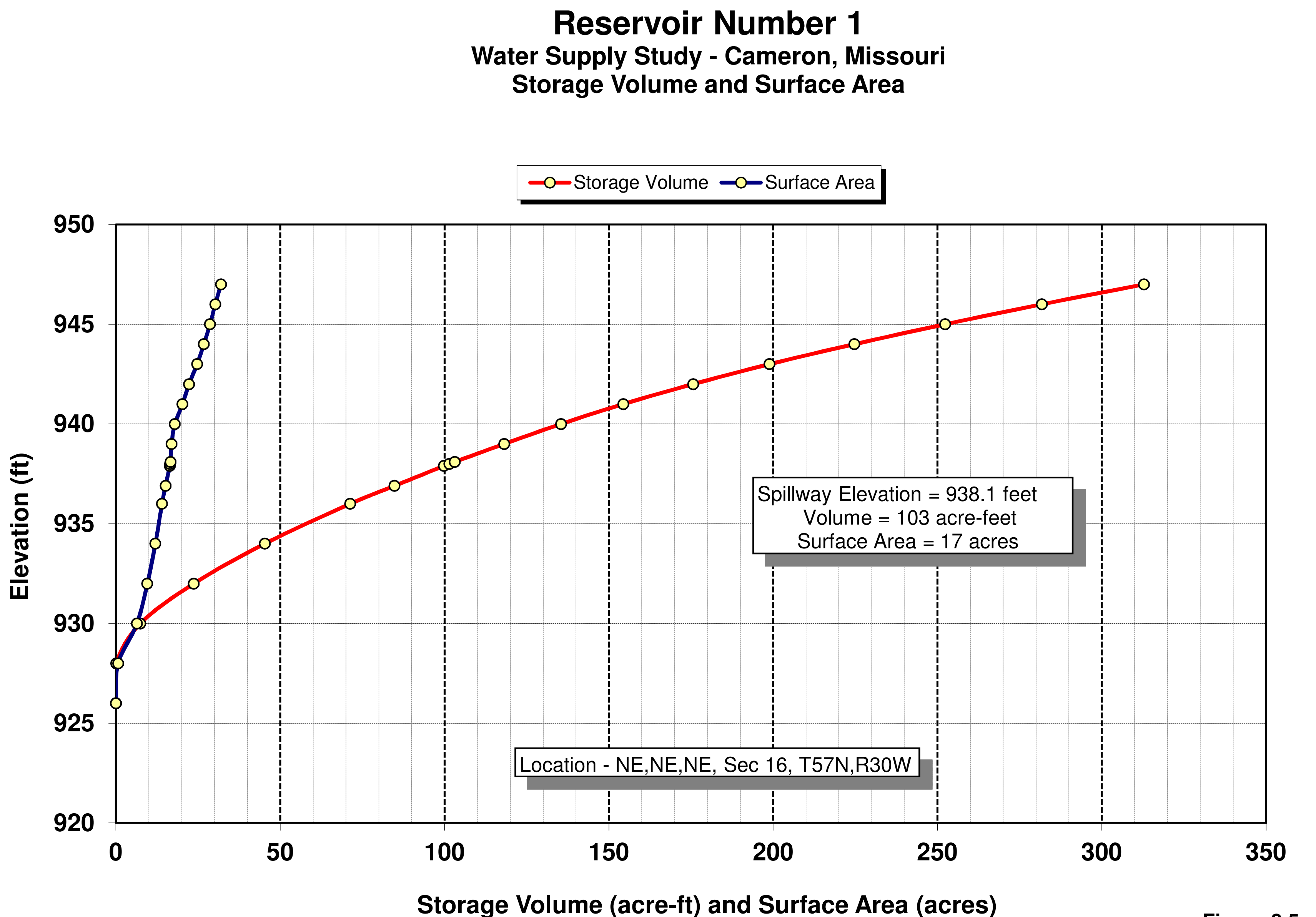

Reservoir Number 1
Water Supply Study - Cameron, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
950
945
940
935
930
925
920
Elevation (ft)
0
50
100
150
200
250
300
350
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 938.1 feet
Volume = 103 acre-feet
Surface Area = 17 acres
Location - NE,NE,NE, Sec 16, T57N,R30W

Figure 8.5.a

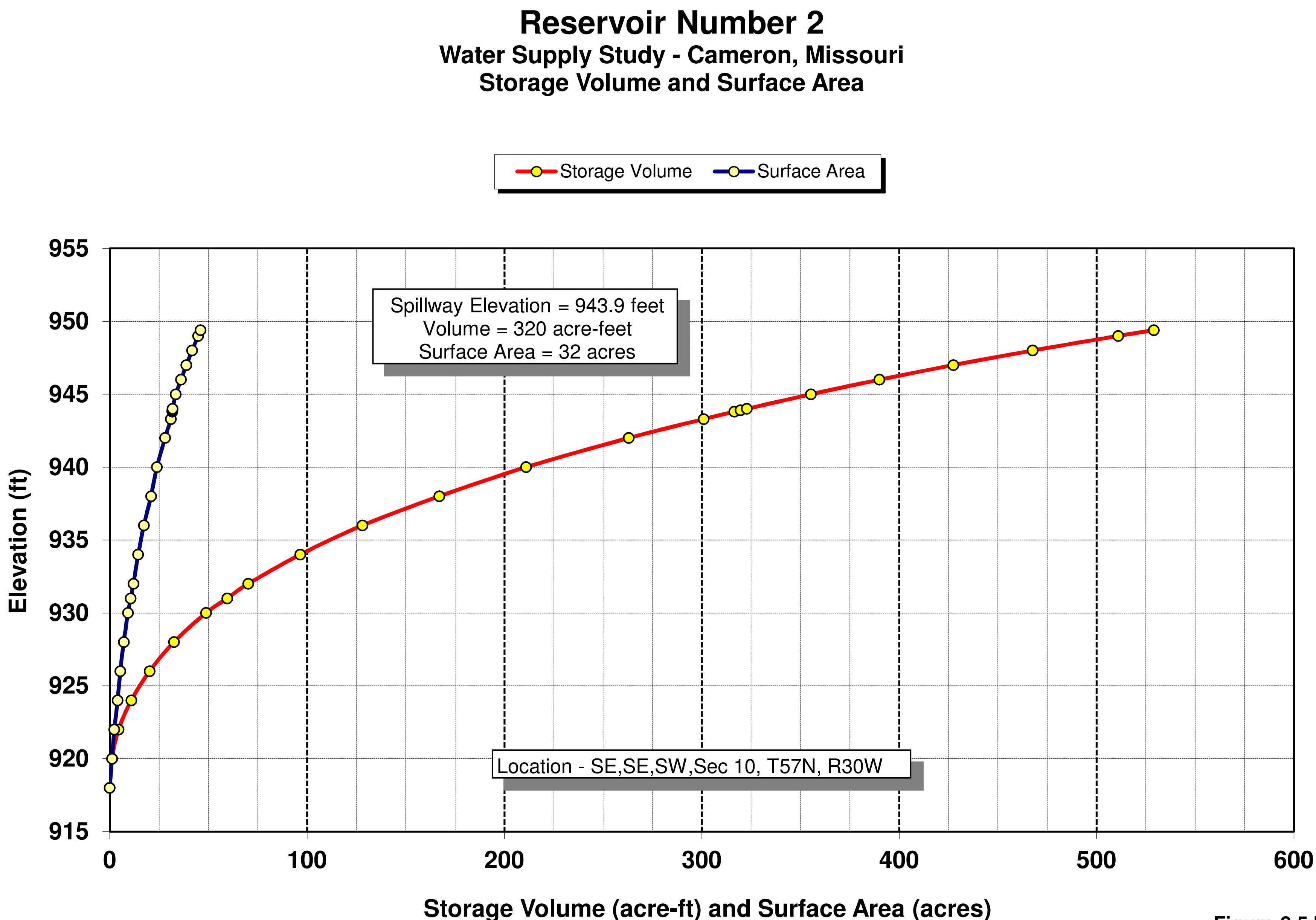

Reservoir Number 2
Water Supply Study - Cameron, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 943.9 feet
Volume = 320 acre-feet
Surface Area = 32 acres
Location - SE,SE,SW,Sec 10, T57N, R30W
Elevation (ft)
955
950
945
940
935
930
925
920
915
0
100
200
300
400
500
600
Storage Volume (acre-ft) and Surface Area (acres)

Figure 8.5.b

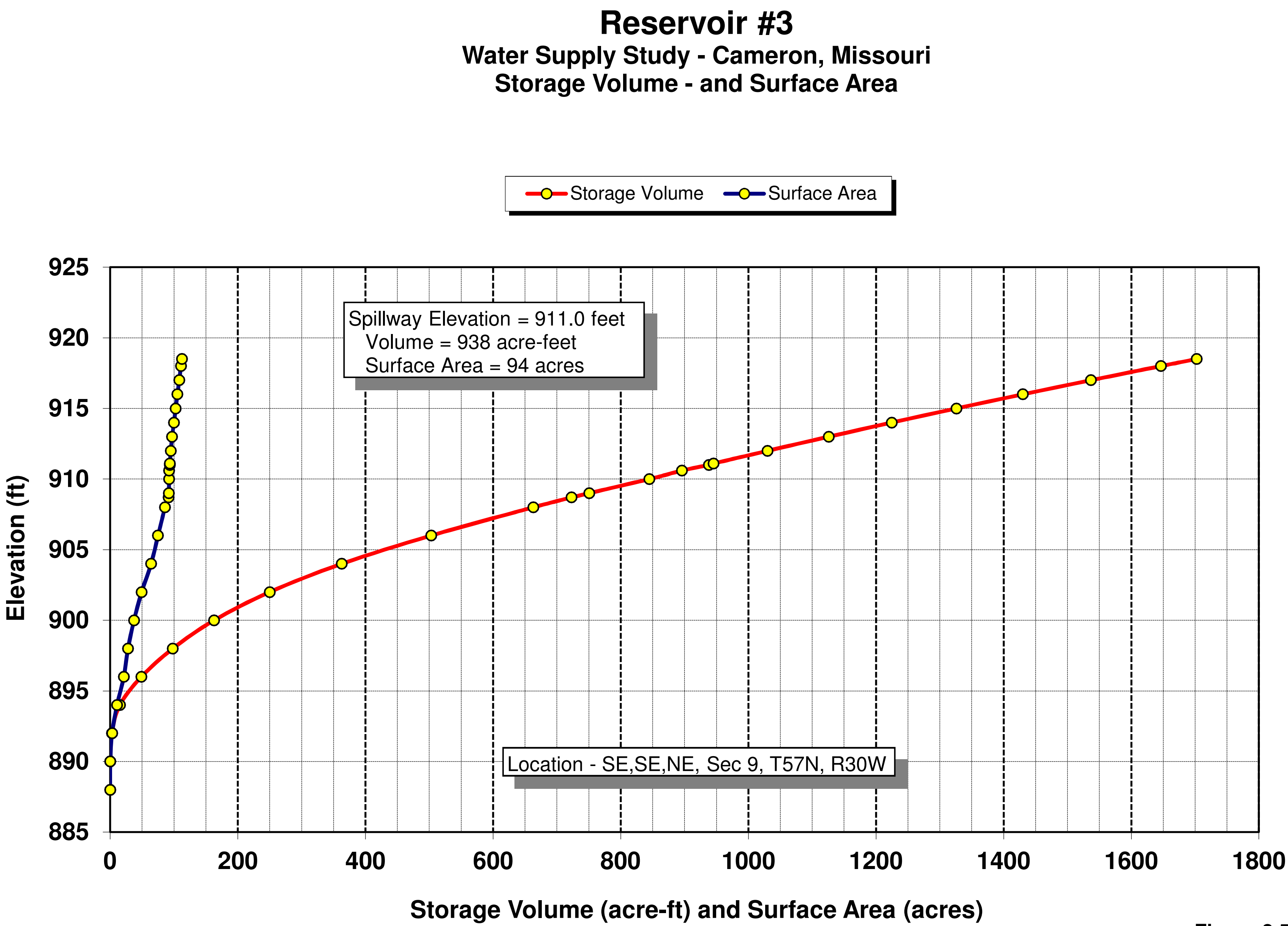

Reservoir #3
Water Supply Study - Cameron, Missouri
Storage Volume - and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 911.0 feet
Volume = 938 acre-feet
Surface Area = 94 acres
Location - SE,SE,NE, Sec 9, T57N, R30W
Elevation (ft)
925
920
915
910
905
900
895
890
885
0
200
400
600
800
1000
1200
1400
1600
1800
Storage Volume (acre-ft) and Surface Area (acres)

Figure 8.5.c

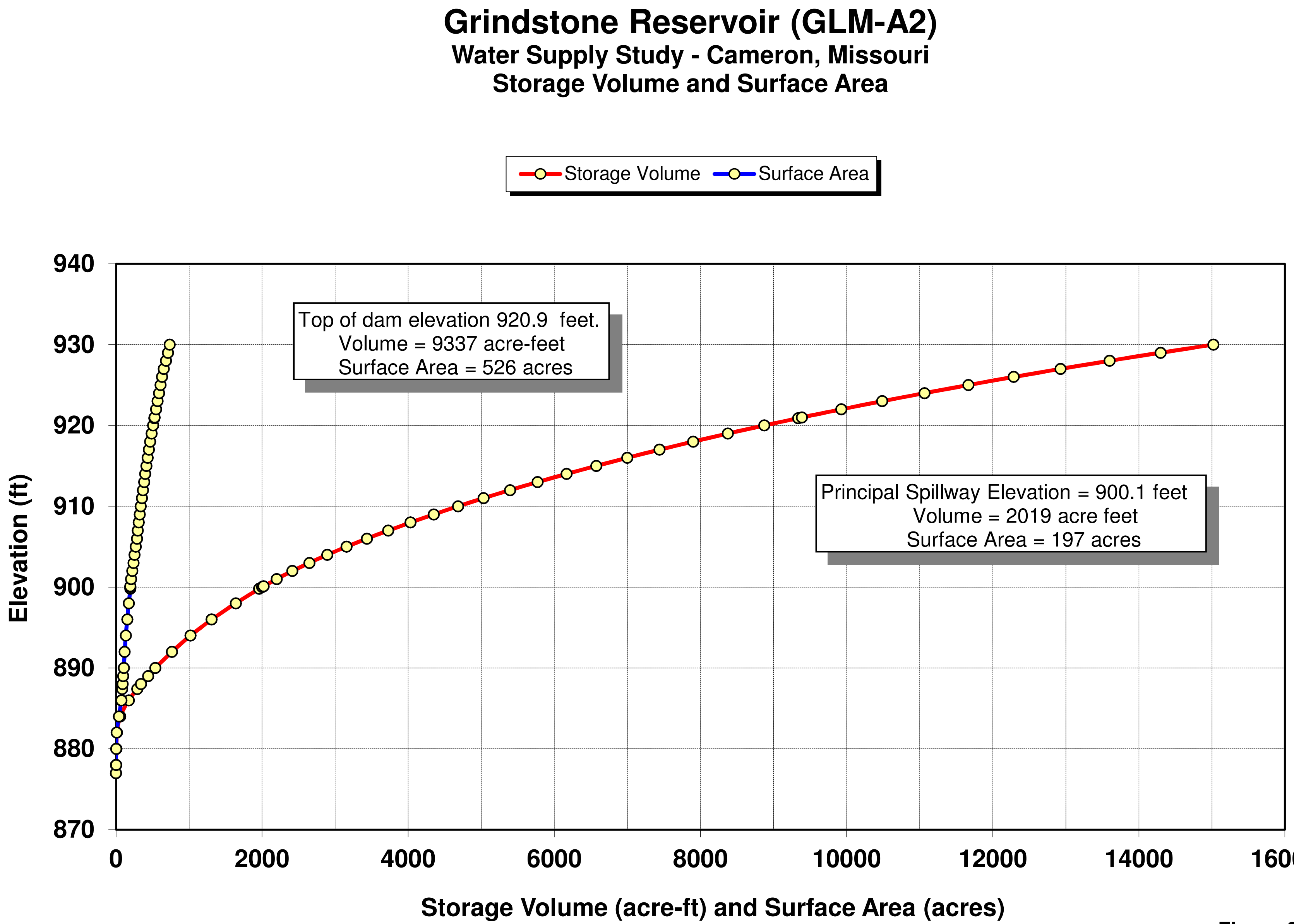

Grindstone Reservoir (GLM-A2)
Water Supply Study - Cameron, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Top of dam elevation 920.9 feet.
Volume = 9337 acre-feet
Surface Area = 526 acres
Principal Spillway Elevation = 900.1 feet
Volume = 2019 acre feet
Surface Area = 197 acres
Elevation (ft)
940
930
920
910
900
890
880
870
0
2000
4000
6000
8000
10000
12000
14000
16000
Storage Volume (acre-ft) and Surface Area (acres)

Figure 8.5.d

E.A. Pape Reservoir
Water Supply Study – Concordia, Missouri
Drought Assessment Analysis

I. Overview

E. A. Pape Lake is located on a tributary to Blackwater River approximately three miles south of Concordia (Figure 9.1). Concordia is located in the southeast corner of Lafayette County Missouri. The reservoir is the primary source of water for Concordia. The combined population served by the Concordia reservoir system is approximately 2,360 with an average consumption of 0.650 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

The trend for water use has shown to be nearly constant between 1988 and 2001, however individual years have fluctuated with a high of 0.63 million gallons per day in 1993 and a low of 0.41 in 1990 and 1996. Water use is reported annually and is maintained in the "Major Water Users Data base" by the Missouri Department of Natural Resources. 2001 total demand of 180,424,873 gallons provides for an average daily demand of 0.494 million gallons per day. Annual water use is illustrated by Figure 9.2.

A request was made to analyze the effects on the reservoir's water storage if the demand were increased to 1.33 million gallons per day. To do that it was necessary to add water from an outside source. Diversion from the Blackwater River into the lake during periods of extended drought was studied to meet this demand. Drainage area at the pump station is approximately 590 square miles and is located approximately 2.1 miles south of E.A. Pape Reservoir. To demonstrate and evaluate the needs for pumping over an extended period, the evaluation period was extended from 1951 through 2000. The following considerations were applied when increasing the yield to 1.33 million gallons per day. Pumping, when storage in the lake falls below 2000 acre-feet (elevation 706.3 feet), is necessary to provide an optimum supply during a drought such as that in the 1950's. During the 1950's 4450 acre-feet was needed to maintain a supply for Concordia, many years required no additional water by pumping. Two stream gages on the river were in existence during all or part of the period analyzed. One gage located upstream of the intake at Valley City existed from 1958 to 1973. The drainage area at this gage was 547 square miles. The downstream gage is at Blue Lick and has a drainage area of 1120 square miles. Data has been gathered at this gage since 1923 and is currently being maintained.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Four analyses were conducted during the study. They are:

1. Remaining storage in the reservoir with a demand of 0.494 million gallons per day.
2. Remaining storage for optimum yield resulting in demand of 0.839 million gallons per day.
3. Remaining storage in the reservoir for demand of 1.33 million gallons per day.
4. Remaining storage in the reservoir after pumping from Blackwater River.

II. Drought assessment summary

E.A. Pape reservoir meets Concordia's 2001 demand of 0.494 million gallons per day with 1056 acre-feet remaining in the reservoir at the end of August 1957. With the lowest useable water at 100 acre-feet the reservoir is able to provide an optimum yield 0.839-million gallons per day.

E.A. Pape reservoir will not meet 1.33 million gallons per day without additional water being added. With maximum pumping of 1000 gallons per minute (gpm) when there is sufficient flow in the river, the demand of 1.33 million gpm can be met with an estimated 430 acre-feet of water storage remaining in the reservoir.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of E.A. Pape Reservoir conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on June 26, 2002. Surface area of the lake and associated storage volume capacities are illustrated in figure 9.4.

E.A. Pape Lake Physical Data

E.A. Pape Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
684.0	0.4	0.2	
686.0	4.7	3.3	
688.0	19.7	26.2	
690.0	32.7	78.2	
692.0	50.9	161.9	
694.0	70.7	281.9	
696.0	89.2	439.3	
698.0	111.0	639.1	
700.0	135.0	886.8	
702.0	156.0	1178.2	
704.0	179.1	1512.6	
706.0	205.3	1896.7	
708.0	238.2	2337.2	
709.3	261.6	2660.1	Lake conditions June 26, 2002
709.6	269.2	2740.2	Spillway

[LIMITS]

Maximum storage…………………………………………………………………2740 acre-feet.
Minimum storage……………………………………………………………………..100 acre-feet.
Drainage basin size……………………………………………………………..8.48 square miles

Initial storage volume was equated to the reservoir at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 2000.

[SEEPAGE]

Seepage from E.A. Pape Lake is approximately 2.0 inches per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation for Concordia was obtained from Lexington, Missouri and supplemented with values from Warrensburg. Average precipitation for the period 1970 through 2000 was 37.2 inches. The record period of drought occurred between 1953 and 1957 with annual precipitation values in Lexington 24.1, 33.6, 39.4, 25.59, 27.88 inches, and 47.1 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Blackwater River stream gauge at Blue Lick for the period 1951 through 1954 and 1970 through 2000, South Fork Blackwater River near Elm for 1954 to 1979.

When this regional runoff value is inconsistent with precipitation values recorded for Lexington, individual storm events were considered. Antecedent rainfall was determined for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from E.A. Pape Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at New Franklin, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to derive this value.

[DEMAND]

Water demand in 2001 was 0.494 million gallons per day, determined from information maintained in the Missouri Department of Natural Resources (Major Water Users Data Base). The total use in 2001 was 180,424,873 gallons.

Demand of 1.33 million gallons per day was provided by local sources.

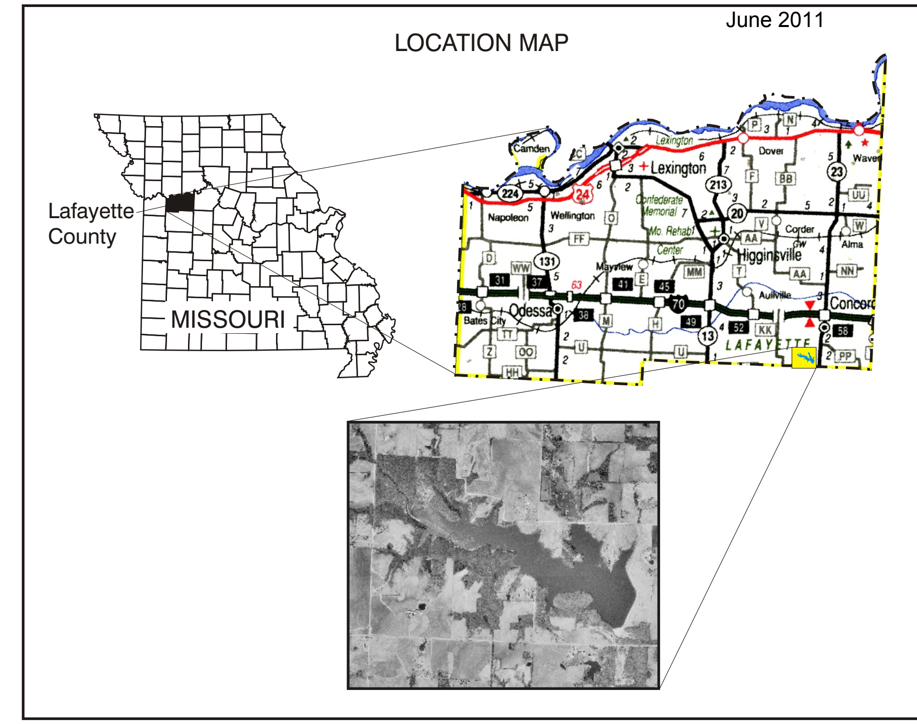
[OTHER]

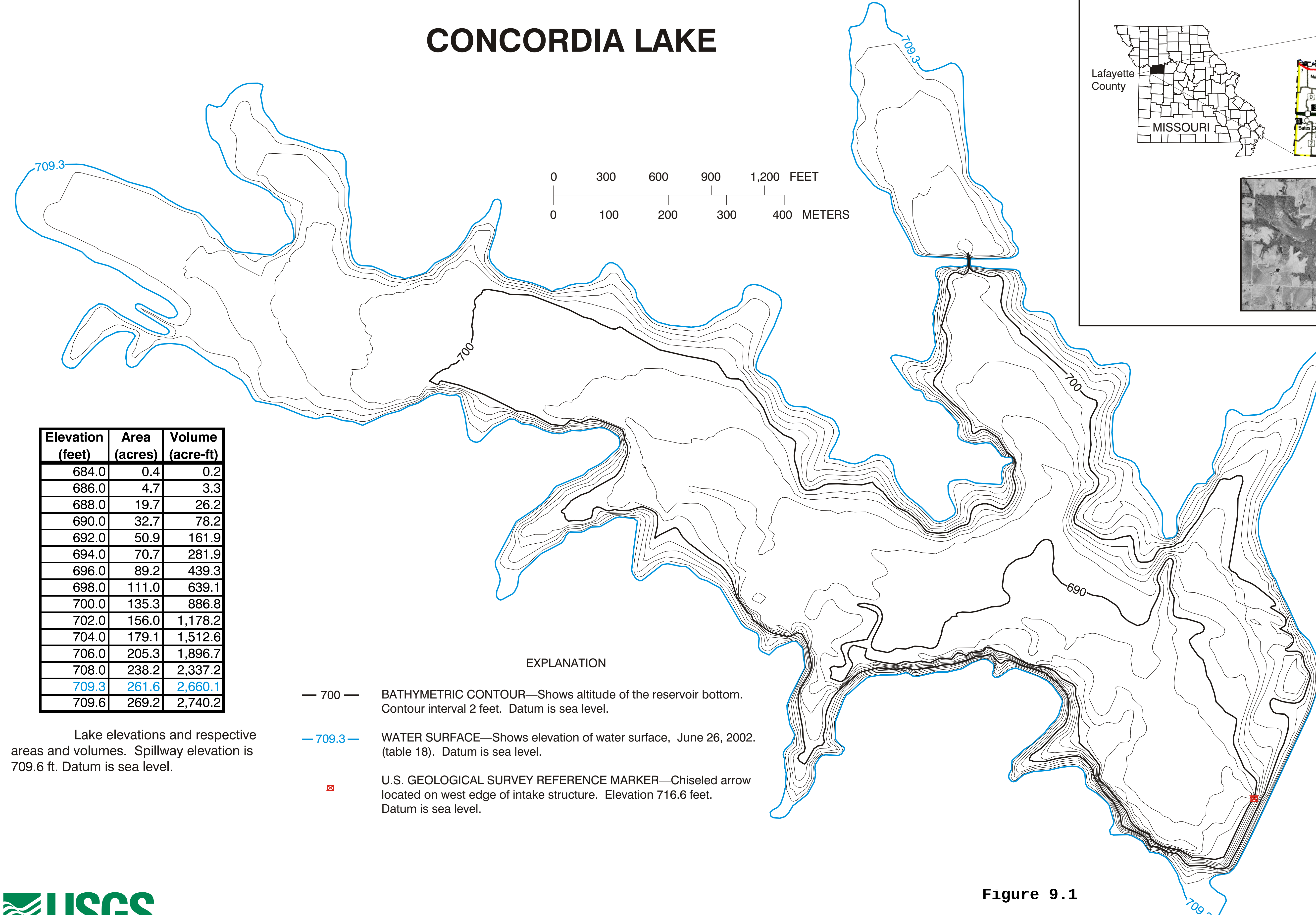
The volume of water added to the system by pumping from Blackwater River into the reservoir.

Various pump sizes were evaluated. The size of pump was optimized to be 1000 gpm. It was assumed that the pump would be able to operate at 75 percent efficiency due of line losses such as friction losses and down time of the pump. Two 500-gpm pumps were evaluated for pumping at lower stream flows but did not make significant difference. To determine if flow in the river is sufficient to allow pumping, the Valley City gage was used for the period of 1958 through 1973

and the Blue Lick gage from 1951 to 1958 and also from 1973 through 2000. Adjustments to stream flow were made based on ratio to drainage area. Only when low flows exceeded 7-day 10-year frequency low flow (the amount to maintain in-stream flow for water quality) was pumping allowed. The 7-day 10 year frequency low flow for both gages were less than 1 cubic feet per second, as a result 1 cubic feet per second was used.

CONCORDIA LAKE





Elevation (feet)	Area (acres)	Volume (acre-ft)
684.0	0.4	0.2
686.0	4.7	3.3
688.0	19.7	26.2
690.0	32.7	78.2
692.0	50.9	161.9
694.0	70.7	281.9
696.0	89.2	439.3
698.0	111.0	639.1
700.0	135.3	886.8
702.0	156.0	1,178.2
704.0	179.1	1,512.6
706.0	205.3	1,896.7
708.0	238.2	2,337.2
709.3	261.6	2,660.1
709.6	269.2	2,740.2

Lake elevations and respective areas and volumes. Spillway elevation is 709.6 ft. Datum is sea level.

EXPLANATION

— 700 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

— 709.3 — WATER SURFACE—Shows elevation of water surface, June 26, 2002. (table 18). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west edge of intake structure. Elevation 716.6 feet. Datum is sea level.

USGS
science for a changing world

Figure 9.1

Bathymetric map and table of areas/volumes of the Concordia Lake near Concordia, Missouri.

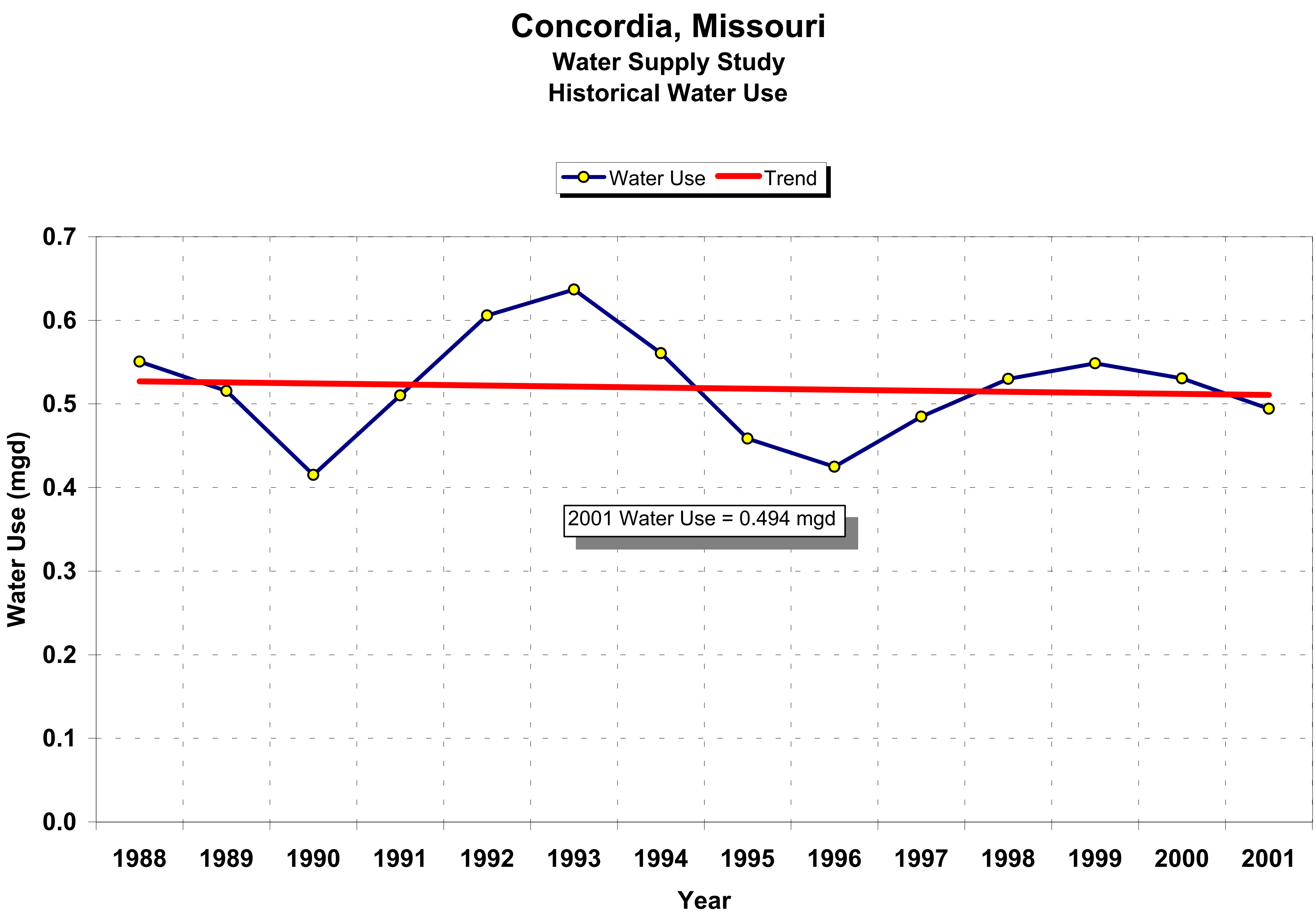

Concordia, Missouri
Water Supply Study
Historical Water Use
Water Use
Trend
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Water Use (mgd)
2001 Water Use = 0.494 mgd
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 9.2

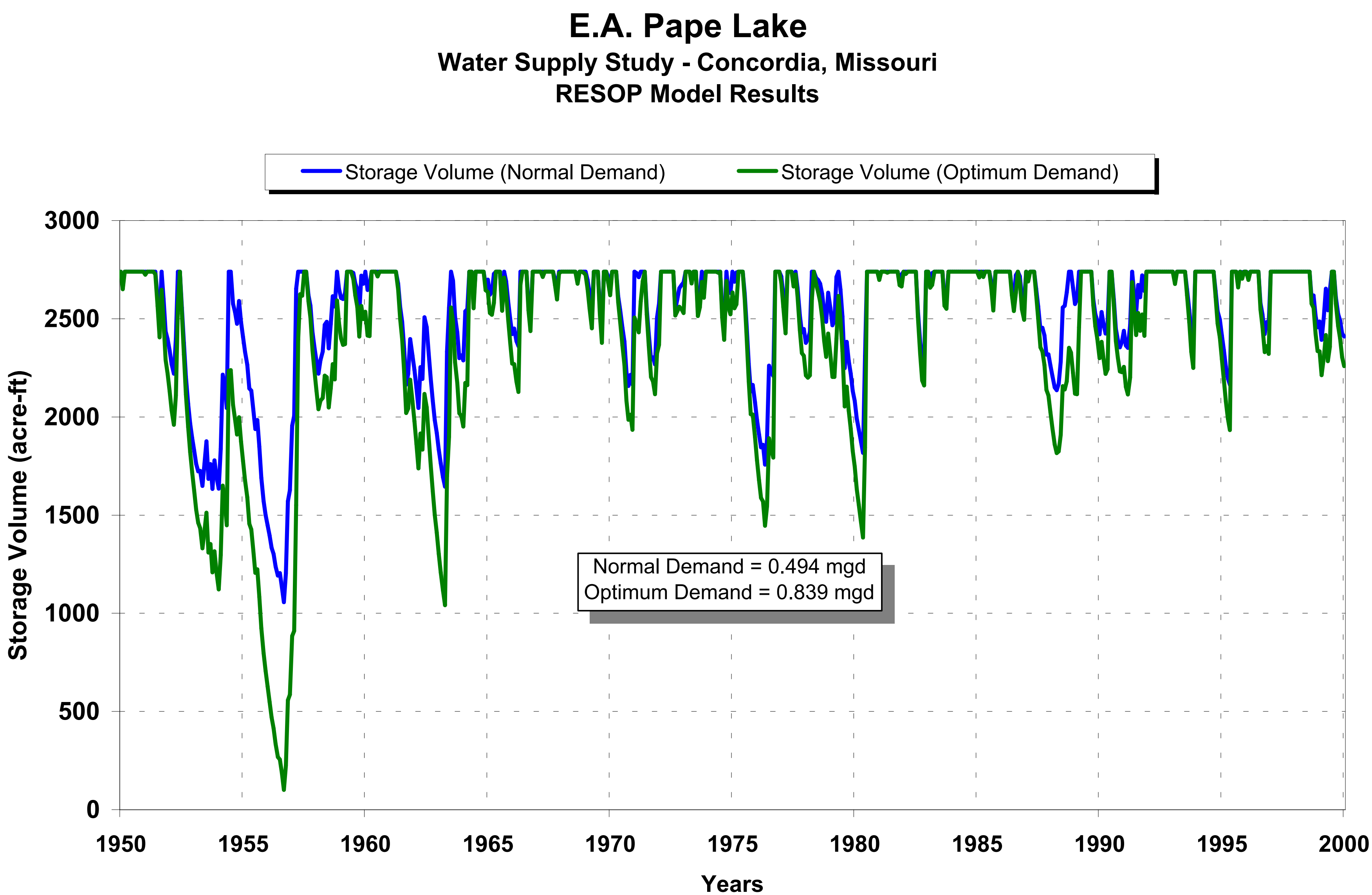

E.A. Pape Lake
Water Supply Study - Concordia, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Storage Volume (acre-ft)
0
500
1000
1500
2000
2500
3000
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Years
Normal Demand = 0.494 mgd
Optimum Demand = 0.839 mgd

Figure 9.3.a

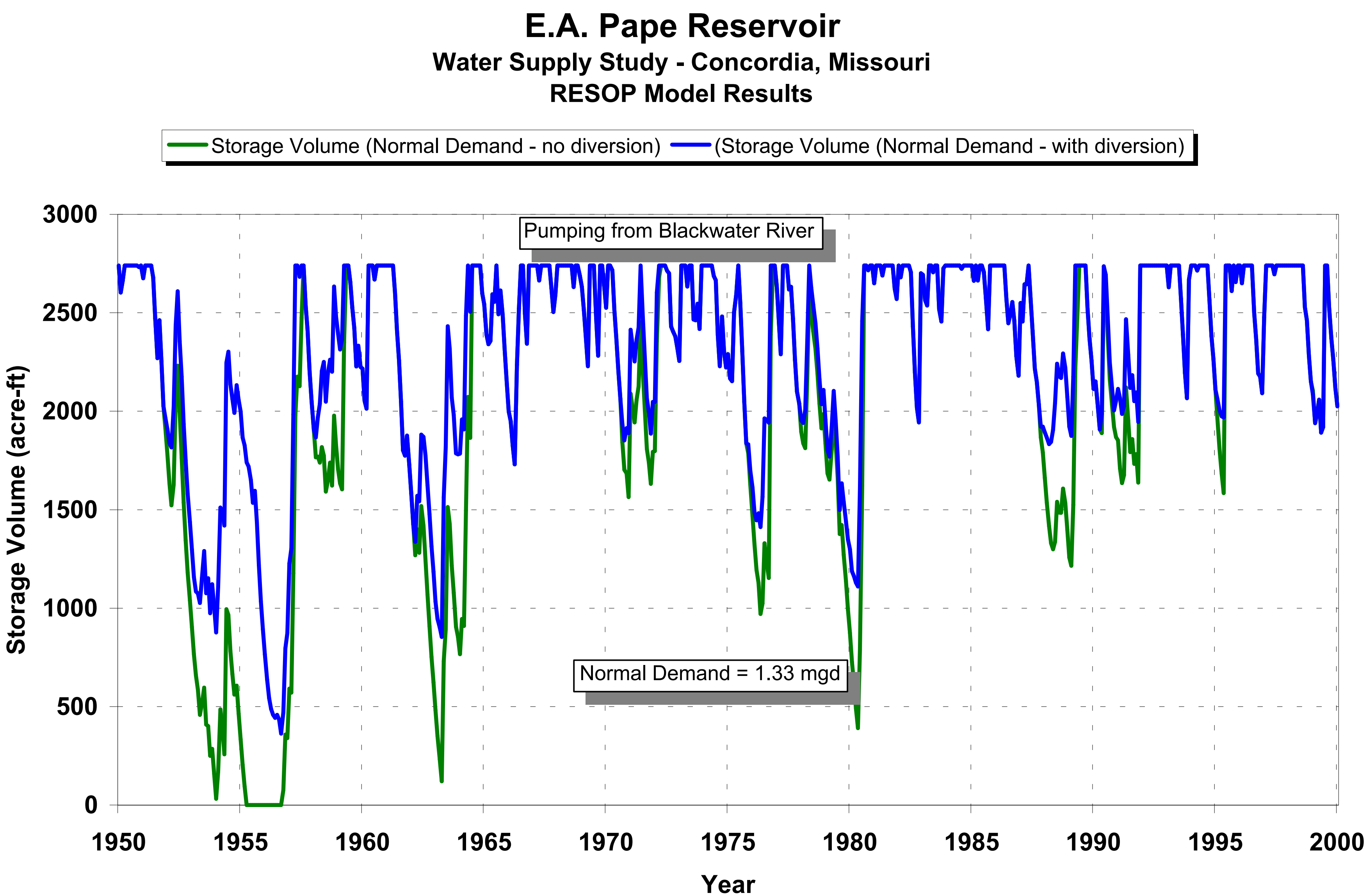

E.A. Pape Reservoir
Water Supply Study - Concordia, Missouri
RESOP Model Results
Storage Volume (Normal Demand - no diversion)
(Storage Volume (Normal Demand - with diversion)
Pumping from Blackwater River
Normal Demand = 1.33 mgd
Storage Volume (acre-ft)
3000
2500
2000
1500
1000
500
0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year

Figure 9.3.b

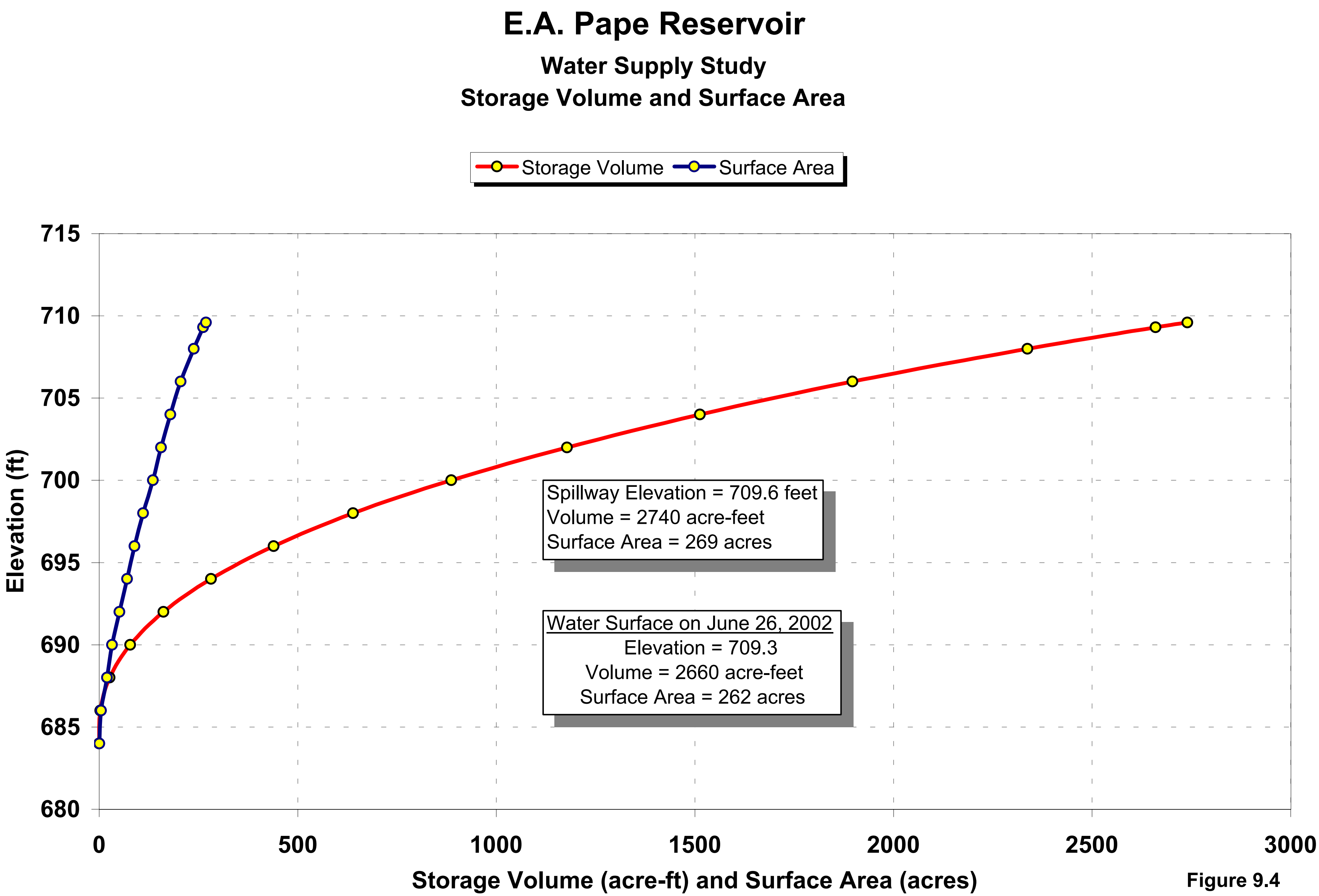

E.A. Pape Reservoir
Water Supply Study
Storage Volume and Surface Area
Storage Volume
Surface Area
Elevation (ft)
715
710
705
700
695
690
685
680
0
500
1000
1500
2000
2500
3000
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 709.6 feet
Volume = 2740 acre-feet
Surface Area = 269 acres
Water Surface on June 26, 2002
Elevation = 709.3
Volume = 2660 acre-feet
Surface Area = 262 acres

Figure 9.4

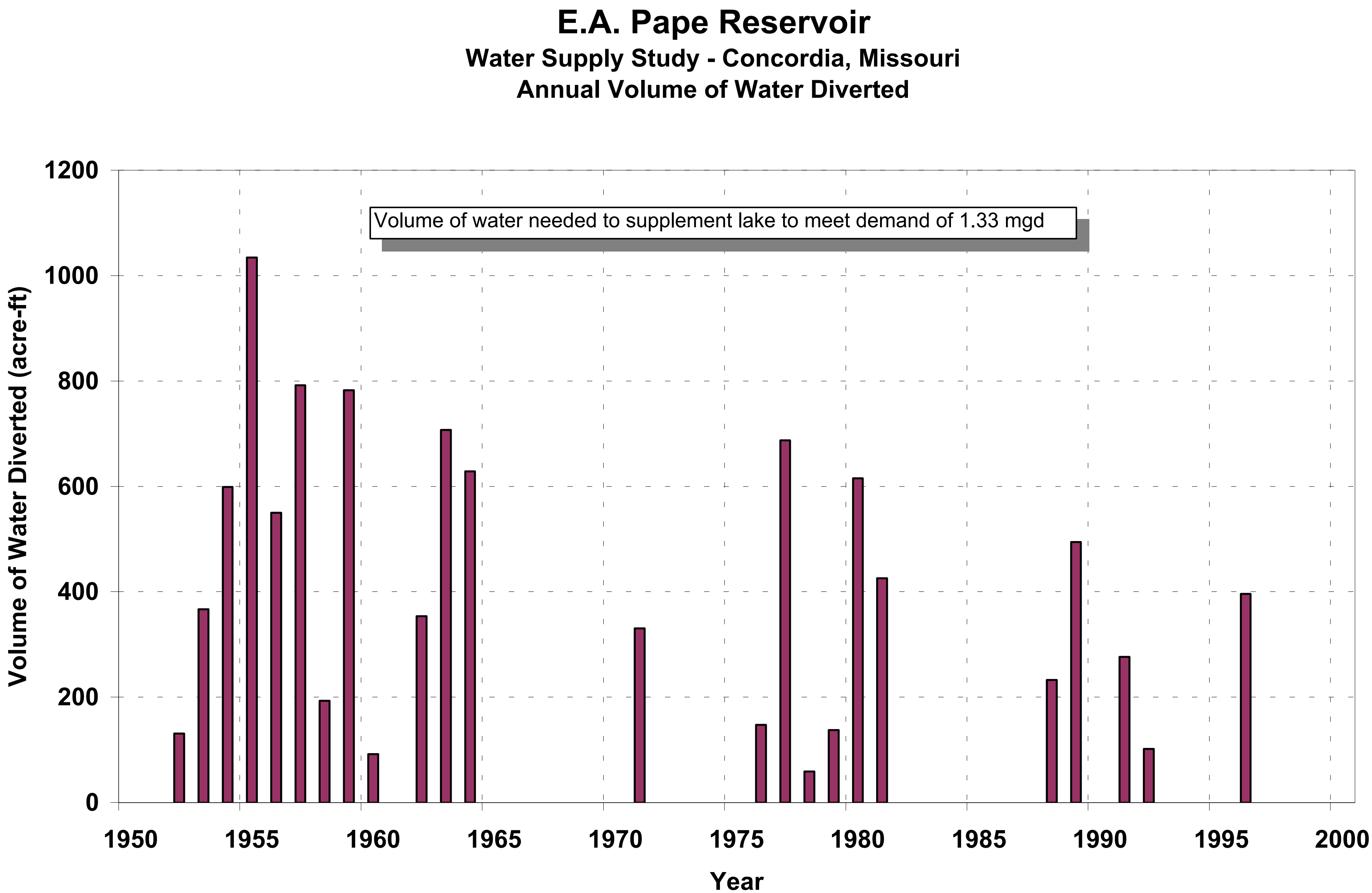

E.A. Pape Reservoir
Water Supply Study - Concordia, Missouri
Annual Volume of Water Diverted
Volume of water needed to supplement lake to meet demand of 1.33 mgd
Volume of Water Diverted (acre-ft)
0
200
400
600
800
1000
1200
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year

Figure 9.5

Creighton Reservoir
Water Supply Study – Creighton, Missouri
Drought Assessment Analysis

I. Overview

Creighton Reservoir (figure 10.1) is located in southeastern Cass County, Missouri, and approximately one and one half miles northwest of the City of Creighton. Creighton Reservoir is the source of water for the City of Creighton. The Creighton Reservoir serves a population of approximately 290 with an estimated water demand of 28,000 gpd. Creighton is not a major water user and they are currently not reporting their water use to Missouri Department of Natural Resources. Usage in the Safe Drinking Water Information System (SDWIS) database indicates they are using an average of 28,000 gallons per day. The plant capacity is reported at 36,000 gpd and the maximum day reported was at a rate of 35,000 gpd.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Creighton Reservoir. The model assumes that ‘Normal’ demand for Creighton is 28,000 gpd and that ‘Optimum’ yield from the lake is 65,500 gpd. Figure 10.3 illustrates these relationships.

II. Drought Assessment Summary

The Creighton Reservoir is capable of meeting Creighton’s year 2000 water use for the drought of the 1950’s. They have been using an average of 28,000 gpd recorded in the SDWIS database. Creighton Reservoir capacity is capable of providing 65,500 gpd.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Creighton Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on June 28, 2003. Surface area of the lake and associated storage volume capacity is illustrated in figure 10.4.

Creighton Lake Physical Data

Creighton Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
806.0	0.09	0.03	
808.0	0.4	0.4	
810.0	1.0	1.7	
812.0	2.2	4.6	
814.0	5.0	11.7	
816.0	7.6	24.5	
818.0	10.0	41.9	
820.0	12.6	64.5	
820.2	13.0	67.1	Lake Conditions on June 28, 2003
822.0	16.6	93.8	
823.0	18.9	111.4	
823.2	19.4	112.9	Spillway

[LIMITS]

Maximum storage ....112.9 acre-feet
Minimum storage ....15 acre-feet
Drainage basin size ....0.83 Square Miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Creighton Lake is approximately 0.75 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Rainfall data came from the Harrisonville, Missouri precipitation gauge for the evaluation period 1951 through 1959.

Average precipitation in Creighton was 42.05 inches between 1970 and 2000. Precipitation values for the drought of record were obtained from Harrisonville, Missouri (approximately 17 miles northwest of Creighton). The most severe drought occurred between 1953 and 1957 with annual precipitation values in Harrisonville of 28.8 inches, 35.7 inches, 28.4 inches, 21.3 inches, and 37.5 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Little Blue River stream gauge near Lake City. Another gauge on Cedar Creek near pleasant View, Missouri was analyzed for comparison. Comparison of the total runoff from the two

gauges resulted in favorable results. Little Blue River runoff volume was chosen to represent Creighton Lake where soil, vegetation and topography was more representative of Creighton Reservoir drainage basin. When this regional runoff value is inconsistent with precipitation values recorded for Creighton, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information

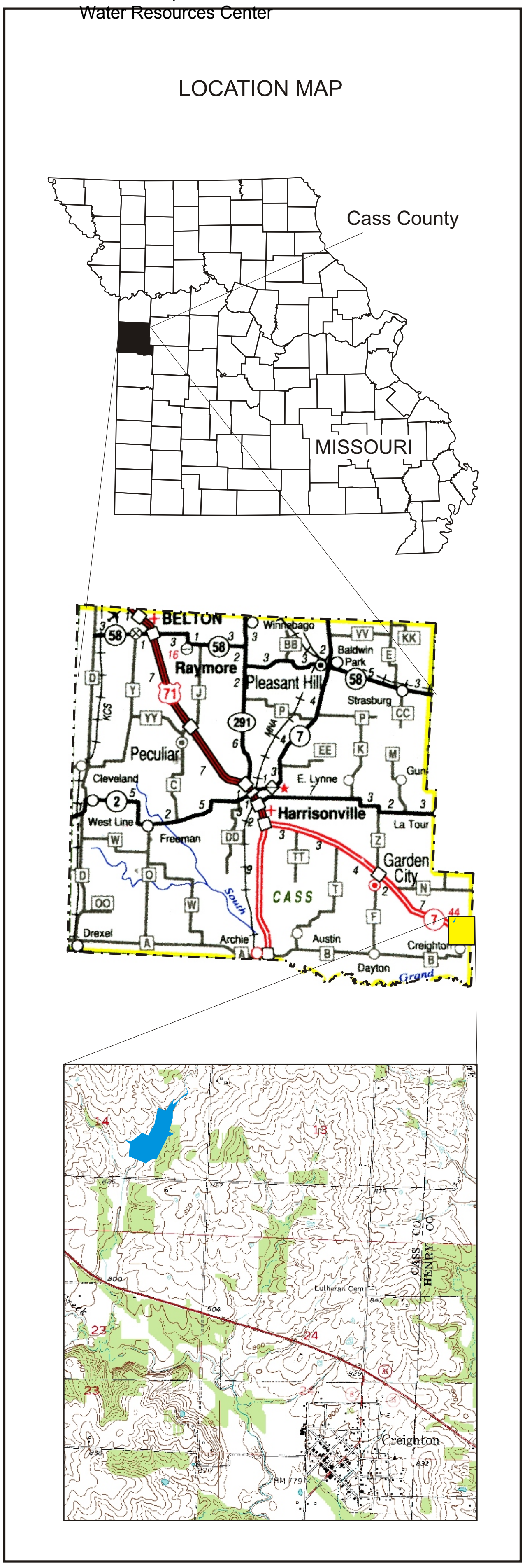
[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Creighton Reservoir due to evaporation. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

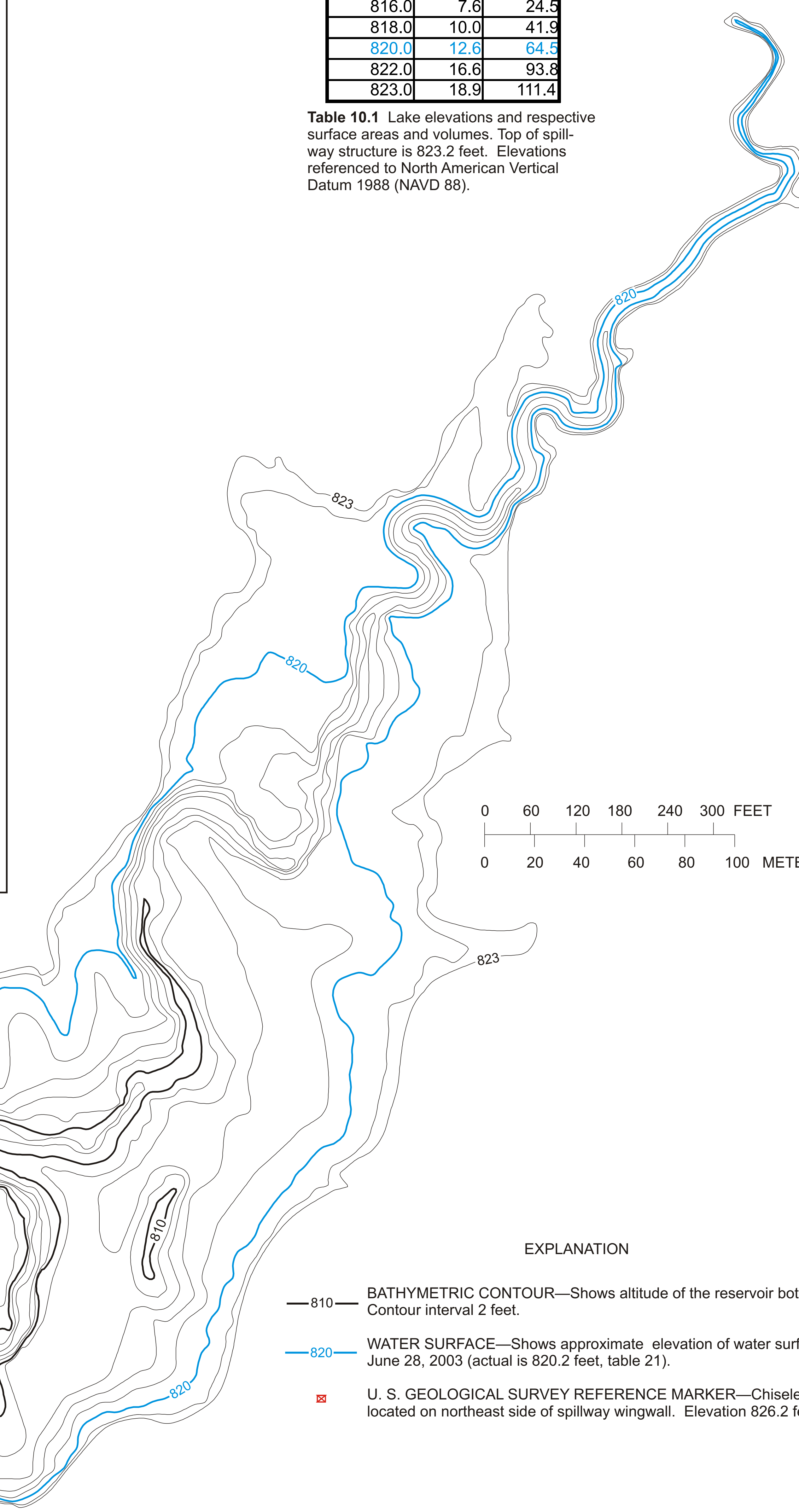
Creighton has not been reporting their water use because they are not considered to be major water users. This RESOP analysis was for the daily use recorded in the SDWIS database. The daily amount recorded is 0.028 million gallons per day. The optimized use would be 0.069 million gallons per day.

CREIGHTON LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
806.0	0.09	0.03
808.0	0.4	0.4
810.0	1.0	1.7
812.0	2.2	4.6
814.0	5.0	11.7
816.0	7.6	24.5
818.0	10.0	41.9
820.0	12.6	64.5
822.0	16.6	93.8
823.0	18.9	111.4

Table 10.1 Lake elevations and respective surface areas and volumes. Top of spillway structure is 823.2 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).




EXPLANATION

810 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

820 — WATER SURFACE—Shows approximate elevation of water surface, June 28, 2003 (actual is 820.2 feet, table 21).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on northeast side of spillway wingwall. Elevation 826.2 feet.

Figure 10.1

USGS
science for a changing world

Bathymetric map and table of areas/volumes of the Creighton Lake near Creighton, Missouri.

In cooperation with Missouri Department of Natural Resources

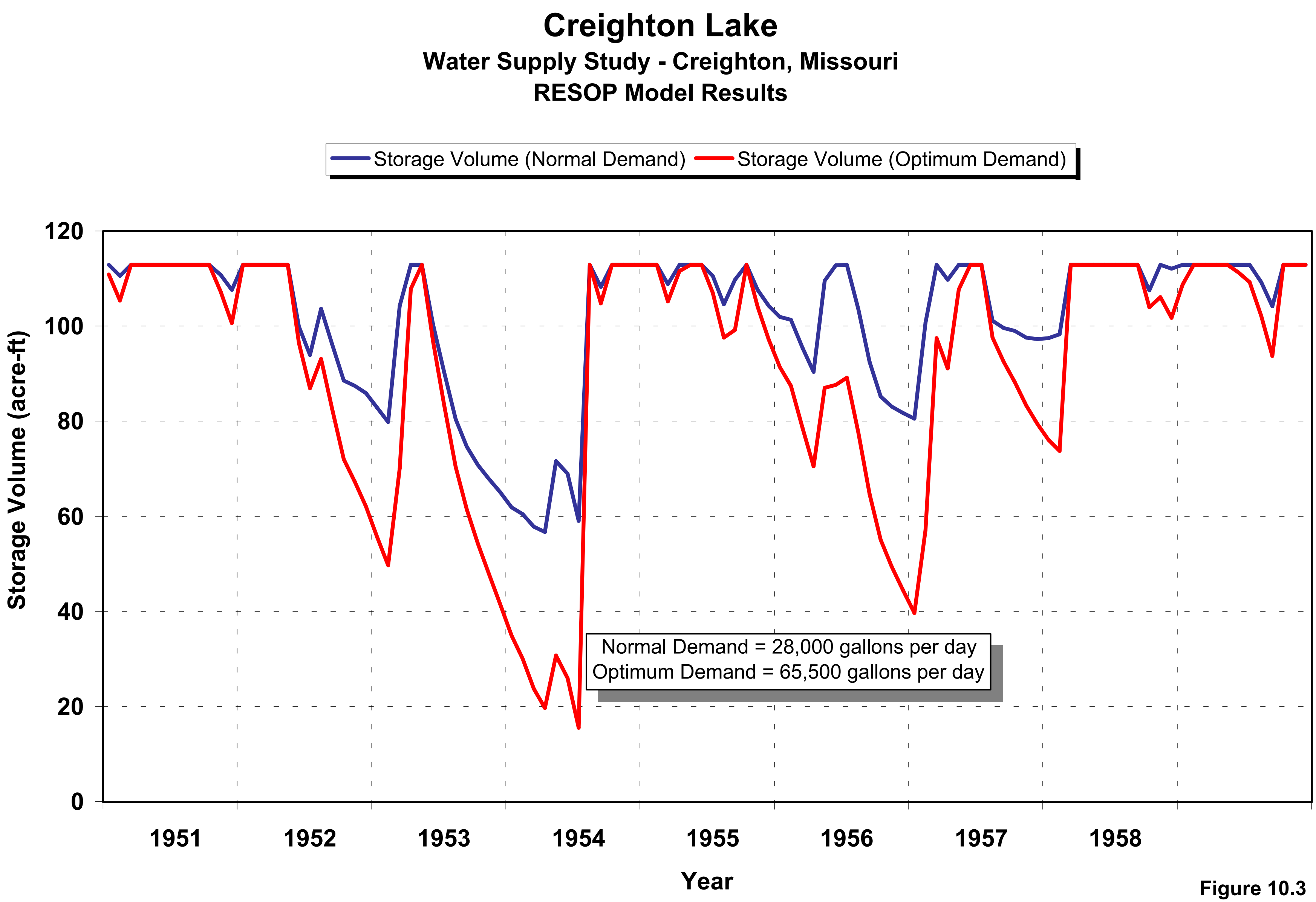

Creighton Lake
Water Supply Study - Creighton, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Storage Volume (acre-ft)
120
100
80
60
40
20
0
Normal Demand = 28,000 gallons per day
Optimum Demand = 65,500 gallons per day
1951
1952
1953
1954
1955
1956
1957
1958
Year

Figure 10.3

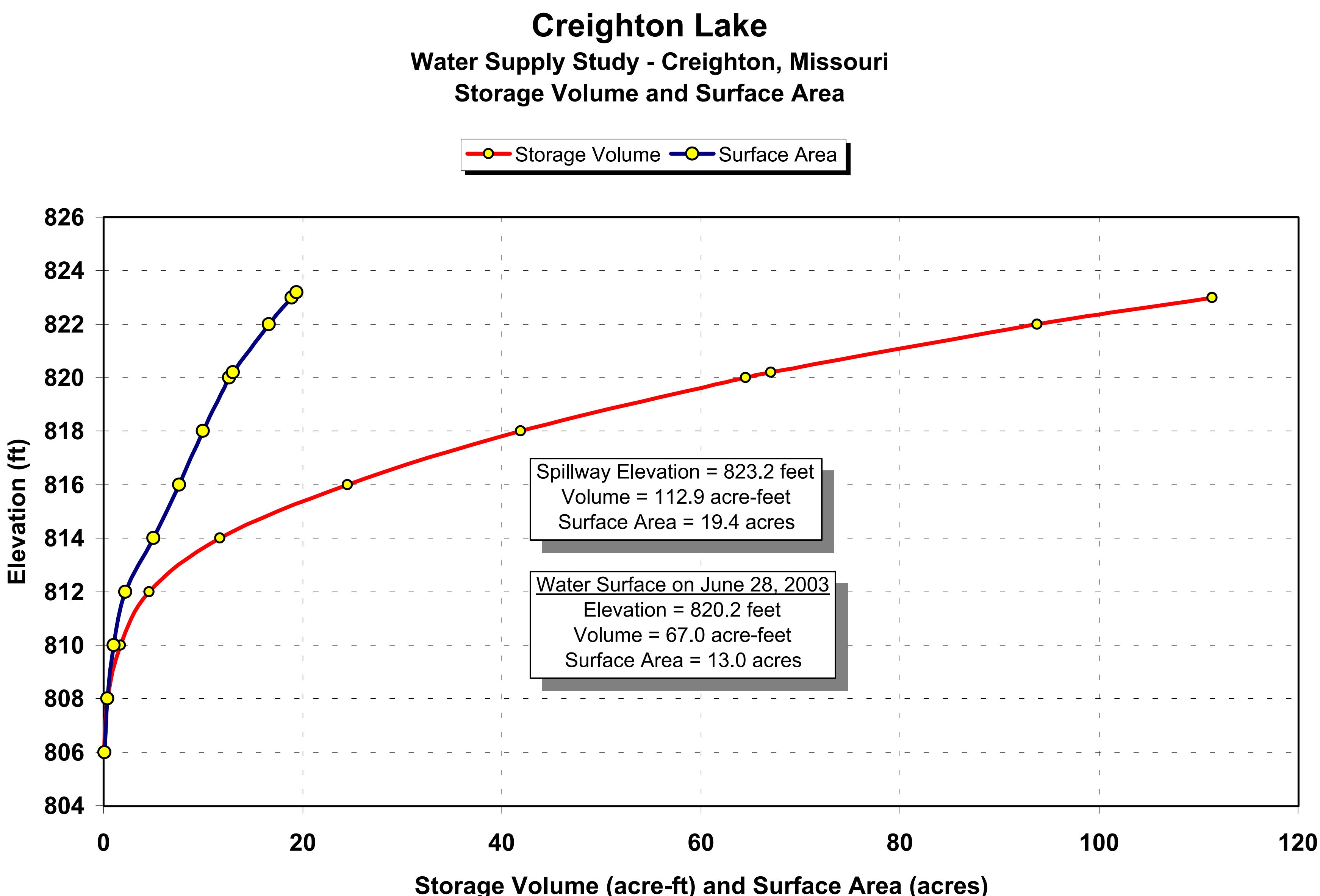

Creighton Lake
Water Supply Study - Creighton, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
826
824
822
820
818
816
814
812
810
808
806
804
Elevation (ft)
0
20
40
60
80
100
120
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 823.2 feet
Volume = 112.9 acre-feet
Surface Area = 19.4 acres
Water Surface on June 28, 2003
Elevation = 820.2 feet
Volume = 67.0 acre-feet
Surface Area = 13.0 acres

Figure 10.4

Dearborn Reservoir
Water Supply Study – Dearborn, Missouri
Drought Assessment

I. Overview

Dearborn Reservoir (figure 11.1) is in south central Buchanan County, Missouri, one-half mile north of the City of Dearborn. Dearborn is located 14 miles east of Edgerton and 25 miles south of St. Joseph, Missouri. Dearborn Reservoir is the primary source of water for the City of Dearborn. The Dearborn Reservoir serves a population of approximately 528 with an estimated water demand of 0.060 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). The reservoir by itself is not capable of meeting Dearborn's needs. To meet the demand water must be diverted from Bee Creek into Dearborn Reservoir. To divert the water a six-inch portable pump is used. Dearborn began purchasing water from Kansas City in 2001. In the future Dearborn Reservoir will be used as a backup.

The City of Dearborn draws water directly from the reservoir to the treatment facility, and the reservoir, itself, is supplemented with water diverted from Bee Creek. Historical demand on the reservoir in 1999 and 2000 was reported to average 62,300 gallons per day. Figure 11.2 illustrates historical water demand on the Dearborn Reservoir. Optimized demand without pumping from Bee Creek is 9670 gallons per day

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Two scenarios were analyzed for the Dearborn reservoir system using the RESOP model:

1. The first scenario assesses the water budget for the reservoir with no additional sources of water (no diversion from Bee Creek). An analysis of 'Normal' demand (actual demand from 2000) was applied to the reservoir during the drought of record to assess potential water deficits. A second analysis for 'Optimum' demand was performed to determine the firm yield from the reservoir without additional water sources - this value represents the viable quantity of water available. Figure 11.3.a illustrates the relationship between these two curves - when actual demand is applied to this scenario the reservoir is drained completely and would not be capable of supplying water to meet demand. The firm yield is insufficient to meet demand.

2. The second scenario analyzes 'Normal' demand and 'Optimum' demand for the Dearborn reservoir system when additional water is diverted to the reservoir from Bee Creek (figure 11.3.b). A stream flow analysis was performed on Bee Creek to estimate the number of days per year that stream flow would exceed 2 cubic feet per second and allow for pumping. Based on this analysis, it was estimated that water diverted from the Bee Creek to the reservoir would allow Dearborn to meet demands except in January, February and March 1954 and again in 1957. When water is diverted, leaving 2 cubic feet per second for in-stream flow needs, the 2000 demand of 62,300 gallons per day, there would be insufficient storage to provide adequate water supply. Optimum demand is 50,500 gallons per day.

II. Drought Assessment Summary

The Dearborn Reservoir is at risk of not meeting the community's demand for water during times of drought (figure 11.3.a). Additional water must be added to meet Dearborn's needs. The 2000 demand on the reservoir was approximately 62,300 gallons per day, and when this demand value is applied to the reservoir, deficits would occur from January 1953 through February 1957. Diverting water from Bee Creek when enough flow exists allowed Dearborn Reservoir to supply sufficient water, except for February 1954 and March 1957, when the reservoir would be emptied. Optimum demand without diversion is only 10,000 gallons per day and with diversion 50,500 gallons per day.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Dearborn Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on July 27, 2000. Surface area of the lake and associated storage volume capacity are illustrated in figure 11.4.

Dearborn Lake Physical Data

Dearborn Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
906.0	0.36	0.05	
908.0	1.84	2.4	
910.0	3.12	7.4	
912.0	4.66	15.2	
914.0	6.38	26.3	
946.0	7.14	40.2	
917.0	7.98	47.9	Lake Conditions July 27, 2000
917.5	8.63	52.0	Spillway

[LIMITS]

Maximum storage ....52.0 acre-feet
Minimum storage ....5 acre-feet
Drainage basin size .... 350 acres

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Dearborn Lake is approximately 2.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation values from Edgerton, Missouri precipitation gauge was used for the evaluation period 1951 through 1959. When precipitation data for Edgerton was missing, data for the St. Joseph precipitation gauge was used.

Average precipitation in St. Joseph was 38.5 inches between 1970 and 2000. The most severe drought occurred between 1953 and 1957 with annual precipitation values in Edgerton of 21.81 inches, 30.75 inches, 30.40 inches, 22.43 inches, and 34.28 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from May of 1950 to September of 1976 at the USGS 06821000 Jenkins Branch at Gower Mo. Jenkins Branch stream is a tributary of the Platte River and is located approximately 26 miles northeast of Dearborn. The drainage area monitored by this stream gauge covers approximately 2.72 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Dearborn, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Dearborn Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

Water demand was obtained from records reported by the Dearborn to Missouri Department of Natural Resources "Major Water Users Data Base". The daily use in 2000 was 62,300 gallons per day, which was used for this analysis. Total use for 2000 was 22.725 million gallons.

Dearborn's 1999 water use was 2,234,800 gallon or and average of 0.062 million gallon per day.

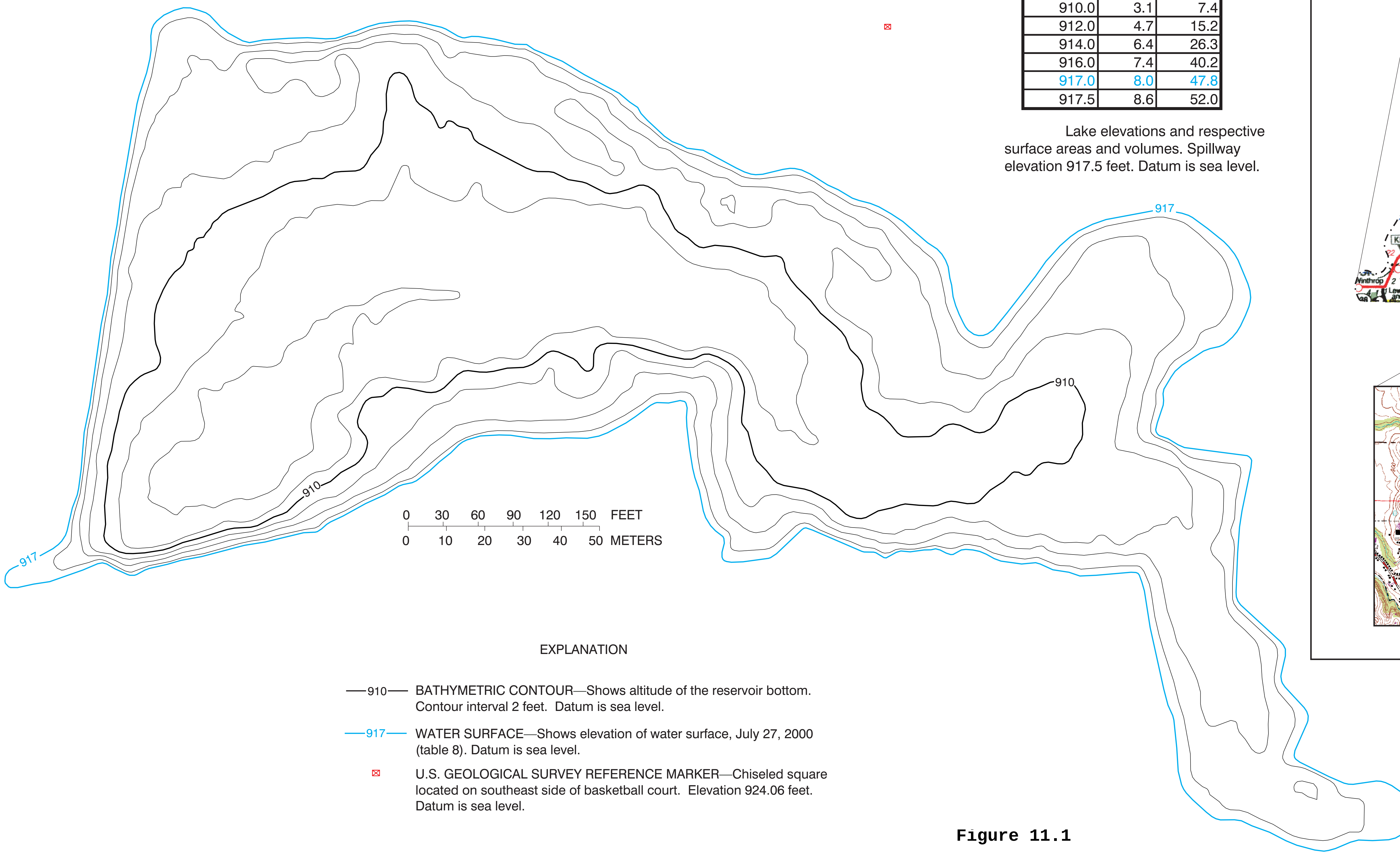
[OTHER]

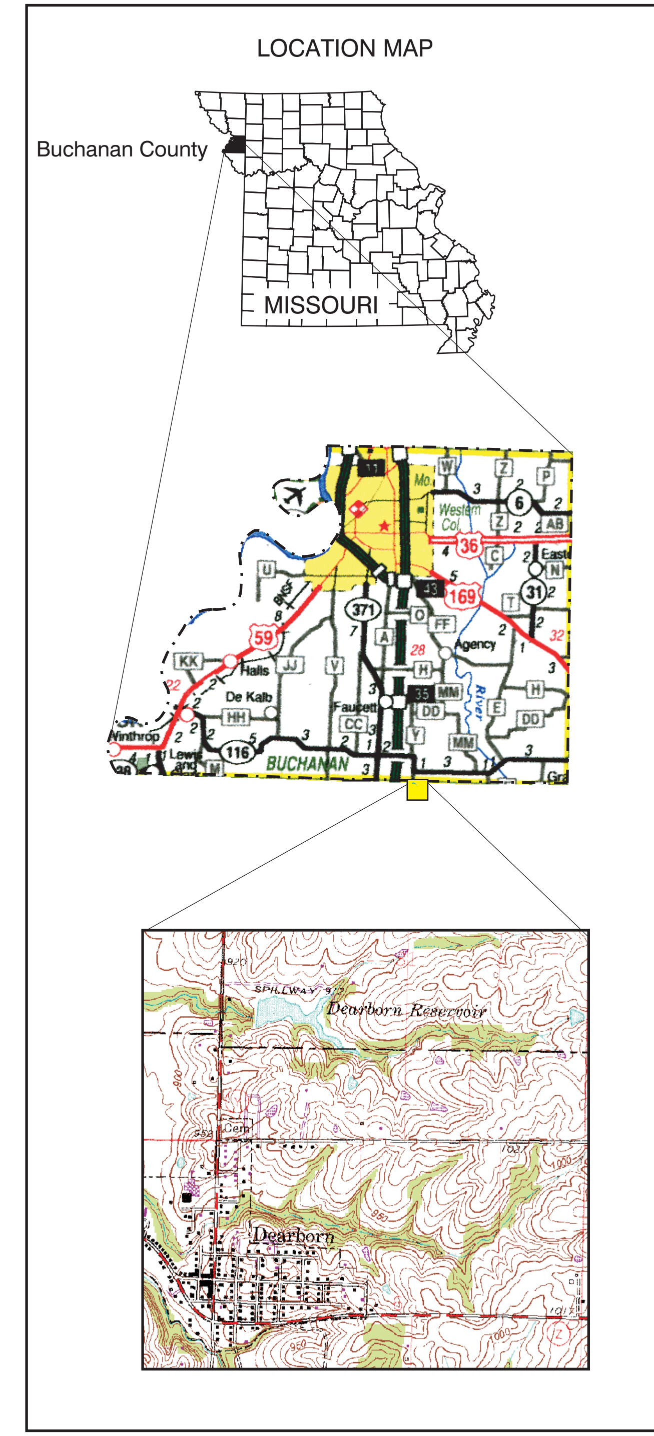
The volume of water diverted from Bee Creek was added as inflow to the reservoir. To determine Bee Creek's ability to supply water to Dearborn Reservoir, daily discharges were determined for the Crooked River stream gauge near Richmond. The Crooked River gauge is about 40 miles South West of Dearborn and has a drainage area is 159 square miles and the drainage area at the point of pumping on Bee Creek is 38 square miles. The Crooked River daily discharges were reduced based on the ratio of drainage areas. Pumping was only planned for flows exceeding 2 cubic feet per second to provide for in-stream flow needs. The rate of pumping, for this analysis, was 500 gallons per minute or 1.1 cubic feet per second.

DEARBORN RESERVOIR

Elevation (feet)	Area (acres)	Volume (acre-ft)
906.0	0.4	0.0
908.0	1.8	2.4
910.0	3.1	7.4
912.0	4.7	15.2
914.0	6.4	26.3
916.0	7.4	40.2
917.0	8.0	47.8
917.5	8.6	52.0

Lake elevations and respective surface areas and volumes. Spillway elevation 917.5 feet. Datum is sea level.





EXPLANATION

—910— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—917— WATER SURFACE—Shows elevation of water surface, July 27, 2000 (table 8). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on southeast side of basketball court. Elevation 924.06 feet. Datum is sea level.

Figure 11.1

USGS
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Bathymetric map and area/volume table for Dearborn Reservoir near Dearborn, Missouri.

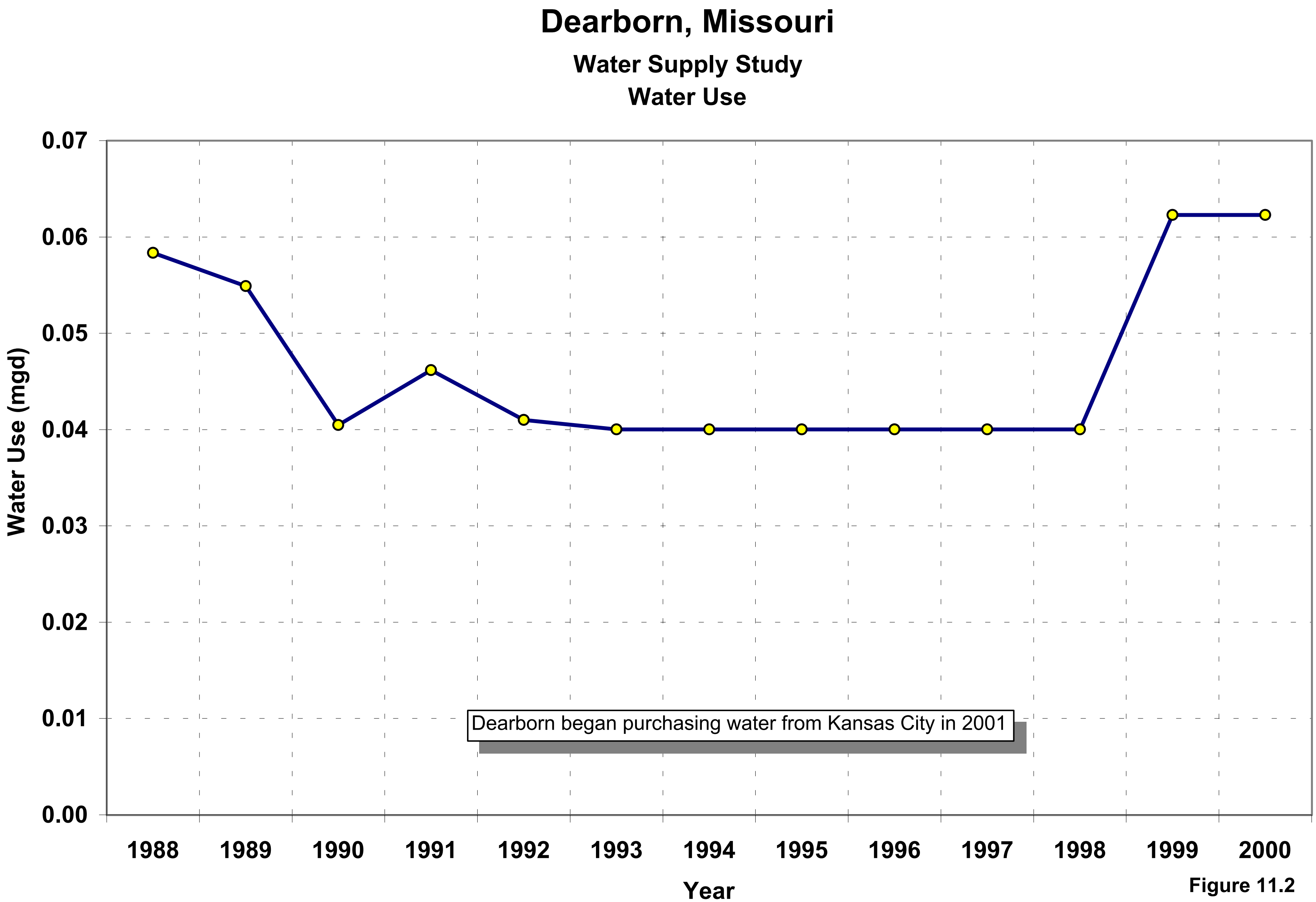

Dearborn, Missouri
Water Supply Study
Water Use
Water Use (mgd)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Dearborn began purchasing water from Kansas City in 2001
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Year

Figure 11.2

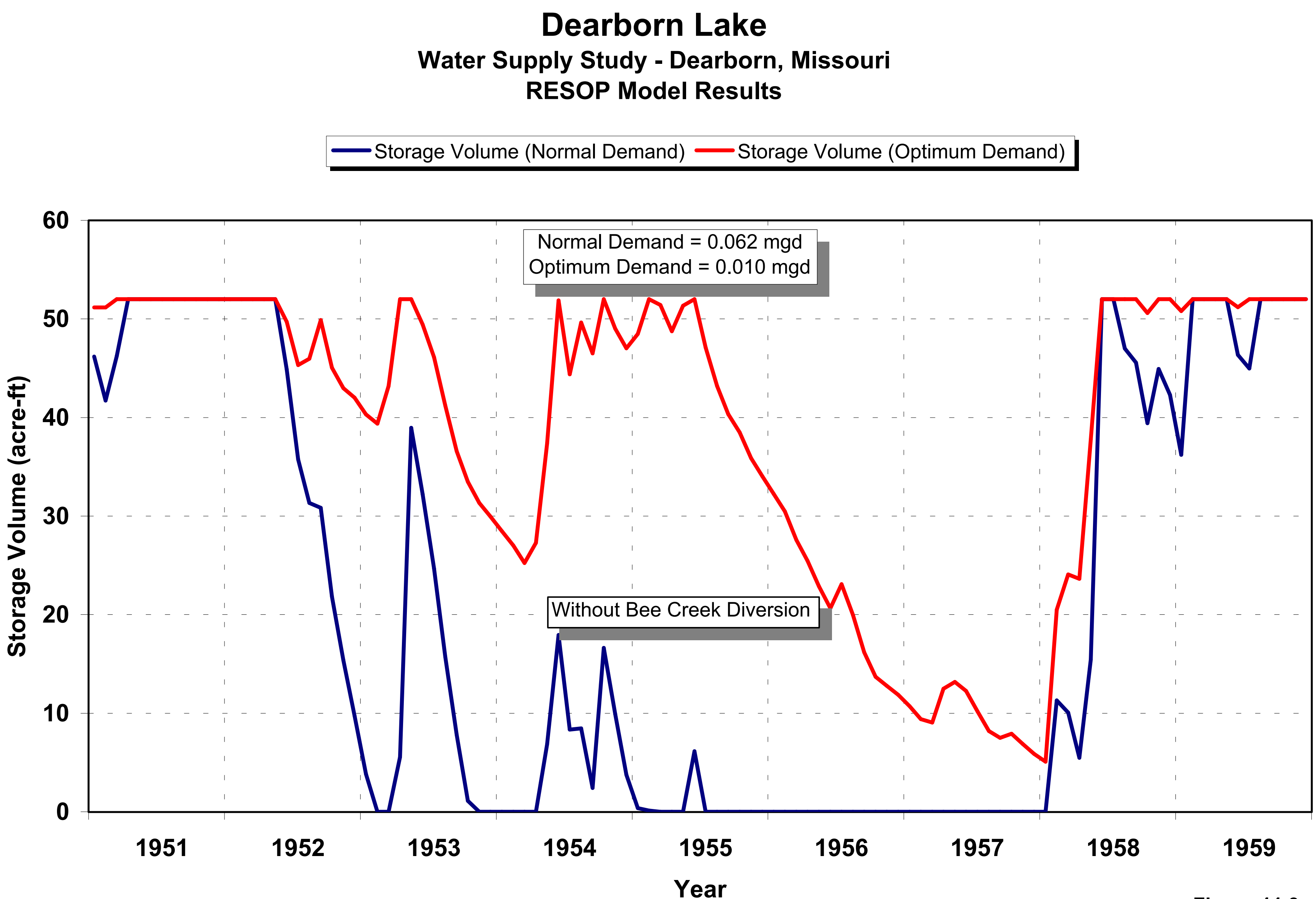

Dearborn Lake
Water Supply Study - Dearborn, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 0.062 mgd
Optimum Demand = 0.010 mgd
Without Bee Creek Diversion
Storage Volume (acre-ft)
60
50
40
30
20
10
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 11.3.a

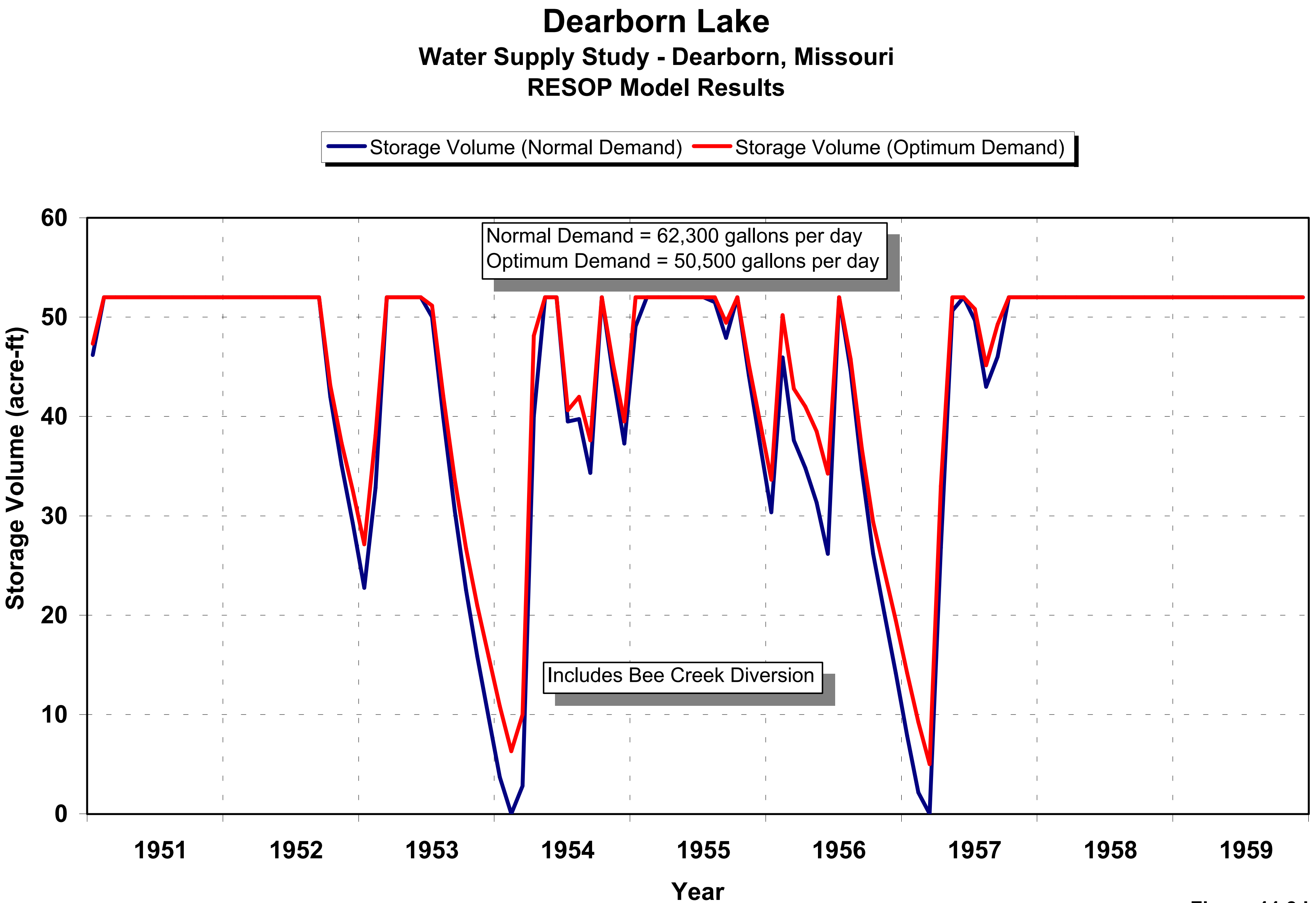

Dearborn Lake
Water Supply Study - Dearborn, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 62,300 gallons per day
Optimum Demand = 50,500 gallons per day
Includes Bee Creek Diversion
Storage Volume (acre-ft)
60
50
40
30
20
10
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 11.3.b

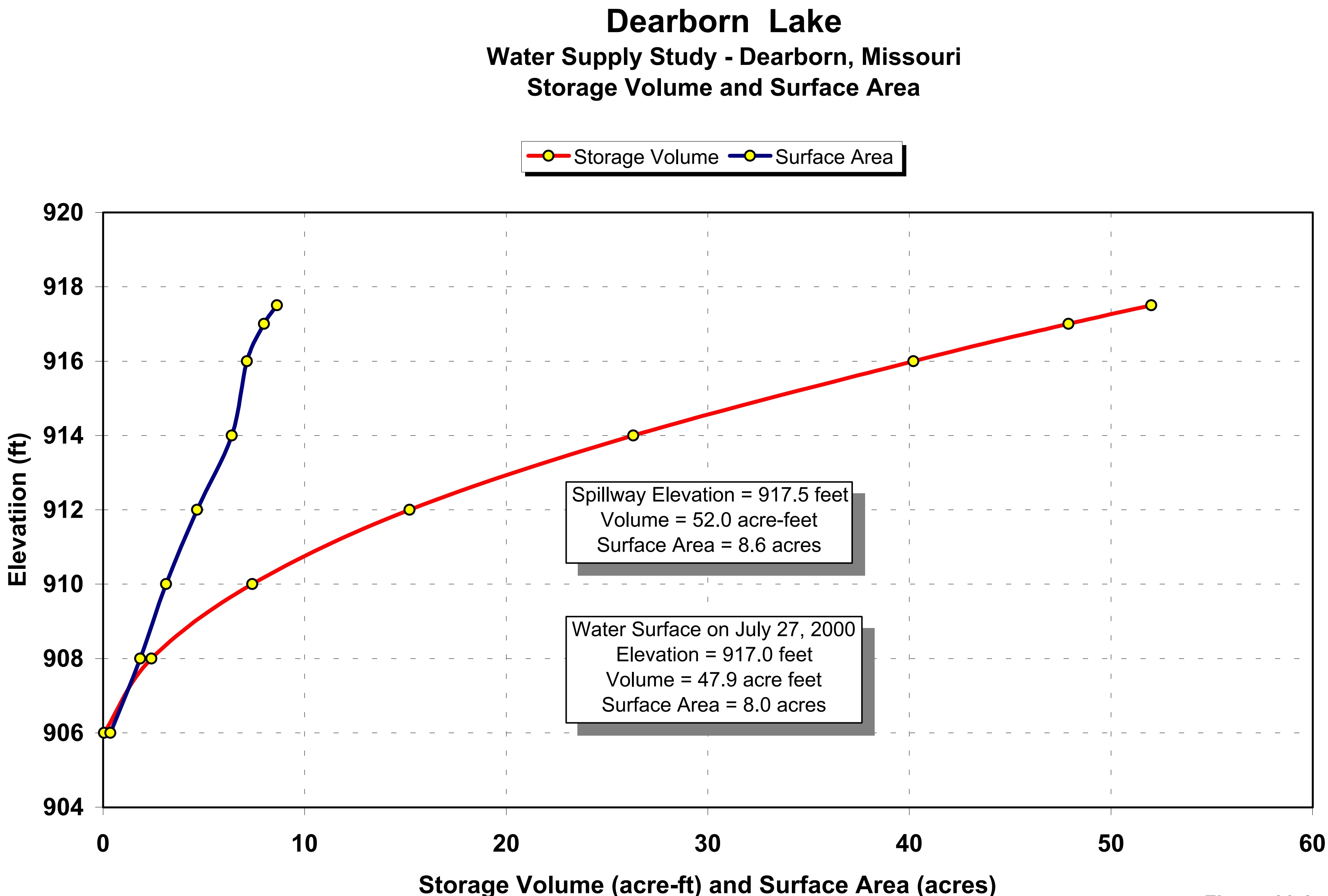

Dearborn Lake
Water Supply Study - Dearborn, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 917.5 feet
Volume = 52.0 acre-feet
Surface Area = 8.6 acres
Water Surface on July 27, 2000
Elevation = 917.0 feet
Volume = 47.9 acre feet
Surface Area = 8.0 acres
Elevatiion (ft)
920
918
916
914
912
910
908
906
904
0
10
20
30
40
50
60
Storage Volume (acre-ft) and Surface Area (acres)

Figure 11.4

Drexel Reservoir #2
Water Supply Study – Drexel, Missouri
Drought Assessment Analysis

Drexel Reservoir #2 (figure 12.1) is located in southwestern Cass County, Missouri, and approximately one mile south of the City of Drexel. Drexel Reservoir #2 is the source of water for the City of Drexel. The Drexel Reservoir #2 serves a population of approximately 1200 with an estimated water demand of 0.103 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). Drexel has 2 lakes and only lake number 2 was surveyed and included in this analysis. The older reservoir #1, which is located at the south edge of Drexel, does not have enough storage capacity to provide a dependable water supply.

Drexel is not a major water user and they are currently not reporting their water use to Missouri Department of Natural Resources for inclusion in the “Major Water Users” database. Usage in the Safe Drinking Water Information System (SDWIS) database indicates they are using an average of 102,600 gallons per day. The plant capacity is reported at 360,000 gallons per day.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Drexel Reservoir. The model assumes that ‘Normal’ demand for Drexel is 102,000 gallons per day and that ‘Optimum’ yield from the lake is 119,000 gallons per day. Figure 12.3 illustrates these relationships.

<u>II. Drought Assessment Summary</u>

Drexel Reservoir #2 is capable of supplying Drexel’s current water needs. The demand on Drexel Reservoir #2 is 0.102 million gallons per day. Water supply in Drexel #2 Reservoir would be critical which may require a backup plan for supplemental water in July 1954 and again January 1957. This analysis indicates there would be 40 acre-feet remaining in the reservoir in 1954 and 70 acre-feet in 1957. The estimated optimum yield is 0.119 million gallons per day.

<u>III. RESOP Model Parameters</u>

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Drexel Lake #2, conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on June 5, 2003. Surface area of the lake and associated storage volume capacities are illustrated in figure 12.4.

Drexel Lake Physical Data

Drexel, Missouri			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
952.0	0.12	0.04	
954.0	1.0	1.0	
956.0	2.4	4.3	
958.0	4.5	11.1	
960.0	7.3	22.6	
962.0	11.2	40.9	
964.0	16.6	68.5	
966.0	23.4	108.3	
967.0	26.8	133.3	
968.0	30.8	162.1	
968.1	31.3	165.2	Lake conditions on June 5, 2003
970.0	40.2	233.4	
972.0	46.7	321.5	
972.5	47.9	345.1	Spillway

[LIMITS]

Maximum Storage……………………………………………………………………345.1acre-feet.
Minimum Storage………………………………………………………………………..10 acre-feet.
Drainage basin size………………………………………………………………………534 acres

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Drexel Lake is approximately 1.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Rainfall data came from the Harrisonville, Missouri precipitation gauge for the evaluation period 1951 through 1959.

Average precipitation in Drexel was 42.05 inches between 1970 and 2000. Precipitation values for the drought of record were obtained from Harrisonville, Missouri (approximately 16 miles northeast of Drexel. The most severe drought occurred between 1953 and 1957 with annual precipitation values in Harrisonville of 28.8 inches, 35.7 inches, 28.4 inches, 21.3 inches, and 37.5 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Little Blue River stream gauge near Lake City. Another gauge on Cedar Creek near pleasant View, Missouri was analyzed for comparison. Comparison of the total runoff from the two gauges

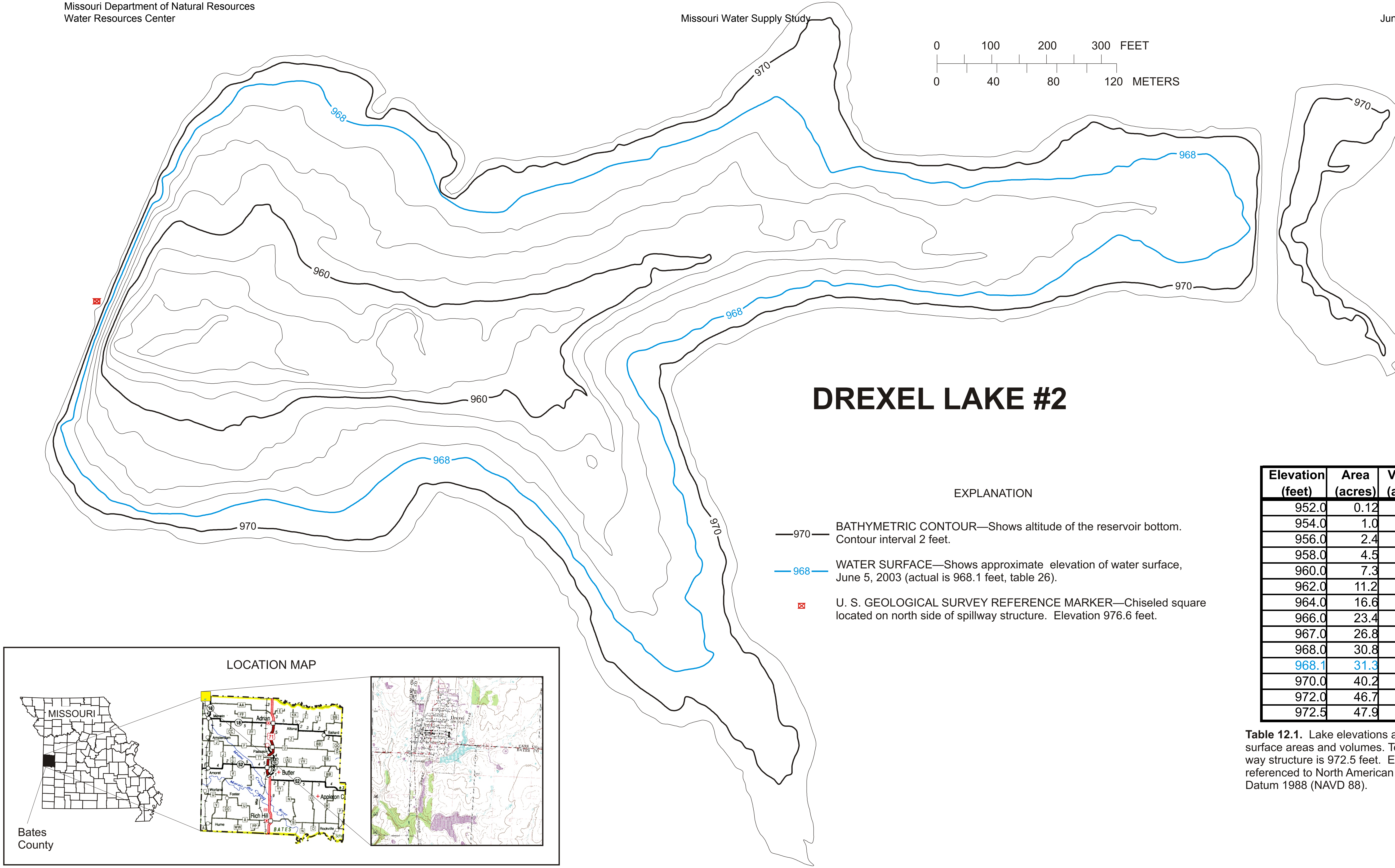
resulted in favorable results. Little Blue River runoff volume was chosen to represent Drexel Lake where soils, vegetation and topography was more representative of Drexel Reservoir drainage basin. When this regional runoff value is inconsistent with precipitation values recorded for Drexel, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Drexel Reservoir due to evaporation. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

Drexel has not been reporting their water use because they were not a major water user. This RESOP run was for the daily use recorded in the SDWIS database. The daily amount for this analysis is 0.102 million gallons per day.



DREXEL LAKE #2

EXPLANATION

—970— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

—968— WATER SURFACE—Shows approximate elevation of water surface, June 5, 2003 (actual is 968.1 feet, table 26).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on north side of spillway structure. Elevation 976.6 feet.

Elevation (feet)	Area (acres)	Volume (acre-ft)
952.0	0.12	0.04
954.0	1.0	1.0
956.0	2.4	4.3
958.0	4.5	11.1
960.0	7.3	22.6
962.0	11.2	40.9
964.0	16.6	68.5
966.0	23.4	108.3
967.0	26.8	133.3
968.0	30.8	162.1
968.1	31.3	165.2
970.0	40.2	233.4
972.0	46.7	321.5
972.5	47.9	345.1

Table 12.1. Lake elevations and respective surface areas and volumes. Top of spillway structure is 972.5 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).

LOCATION MAP

Figure 12.1

Bathymetric map and table of areas/volumes of Drexel Lake #2 near Drexel, Missouri.

USGS science for a changing world

In cooperation with Missouri Department of Natural Resources

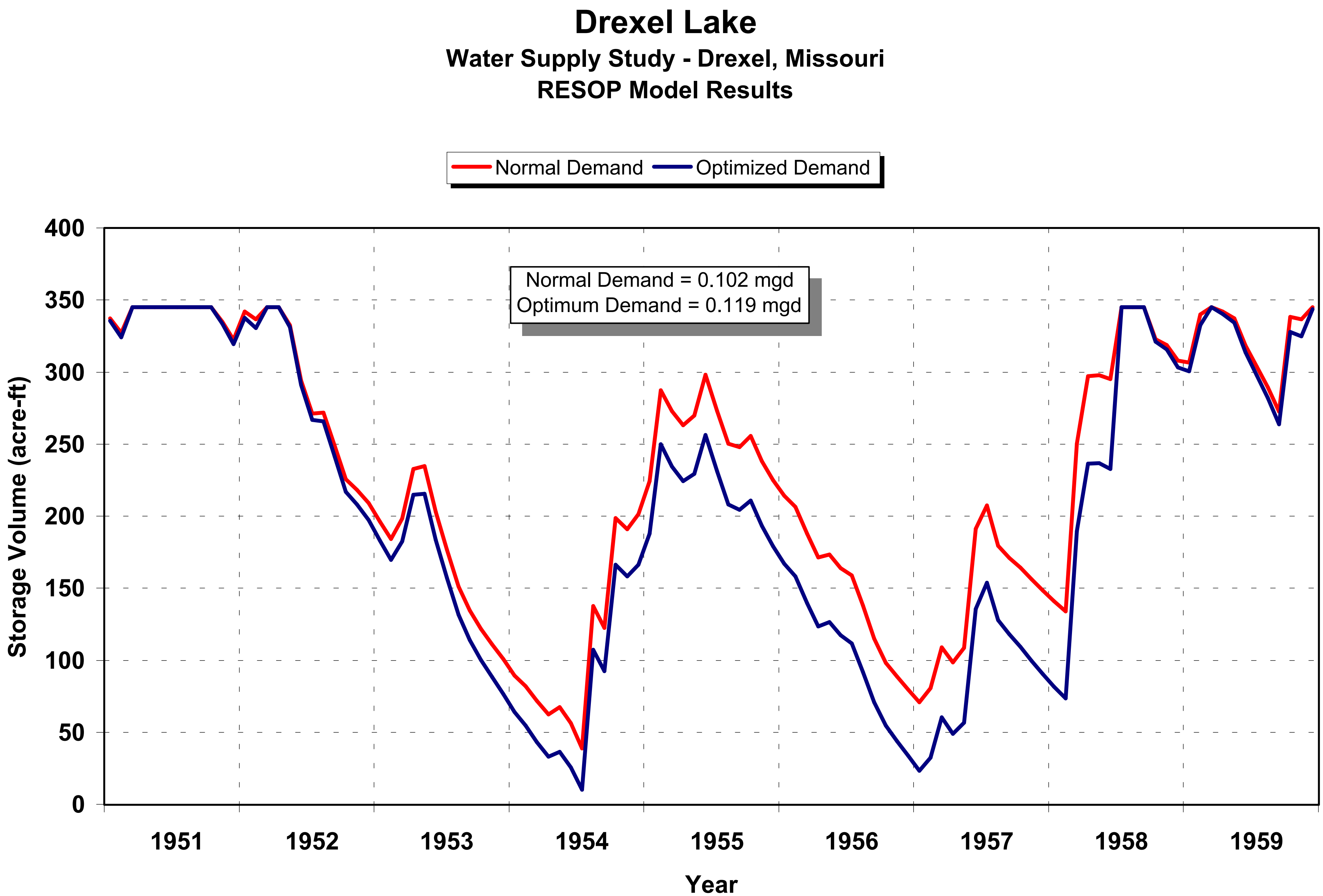

Drexel Lake
Water Supply Study - Drexel, Missouri
RESOP Model Results
Normal Demand
Optimized Demand
Normal Demand = 0.102 mgd
Optimum Demand = 0.119 mgd
Storage Volume (acre-ft)
0
50
100
150
200
250
300
350
400
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 12.3

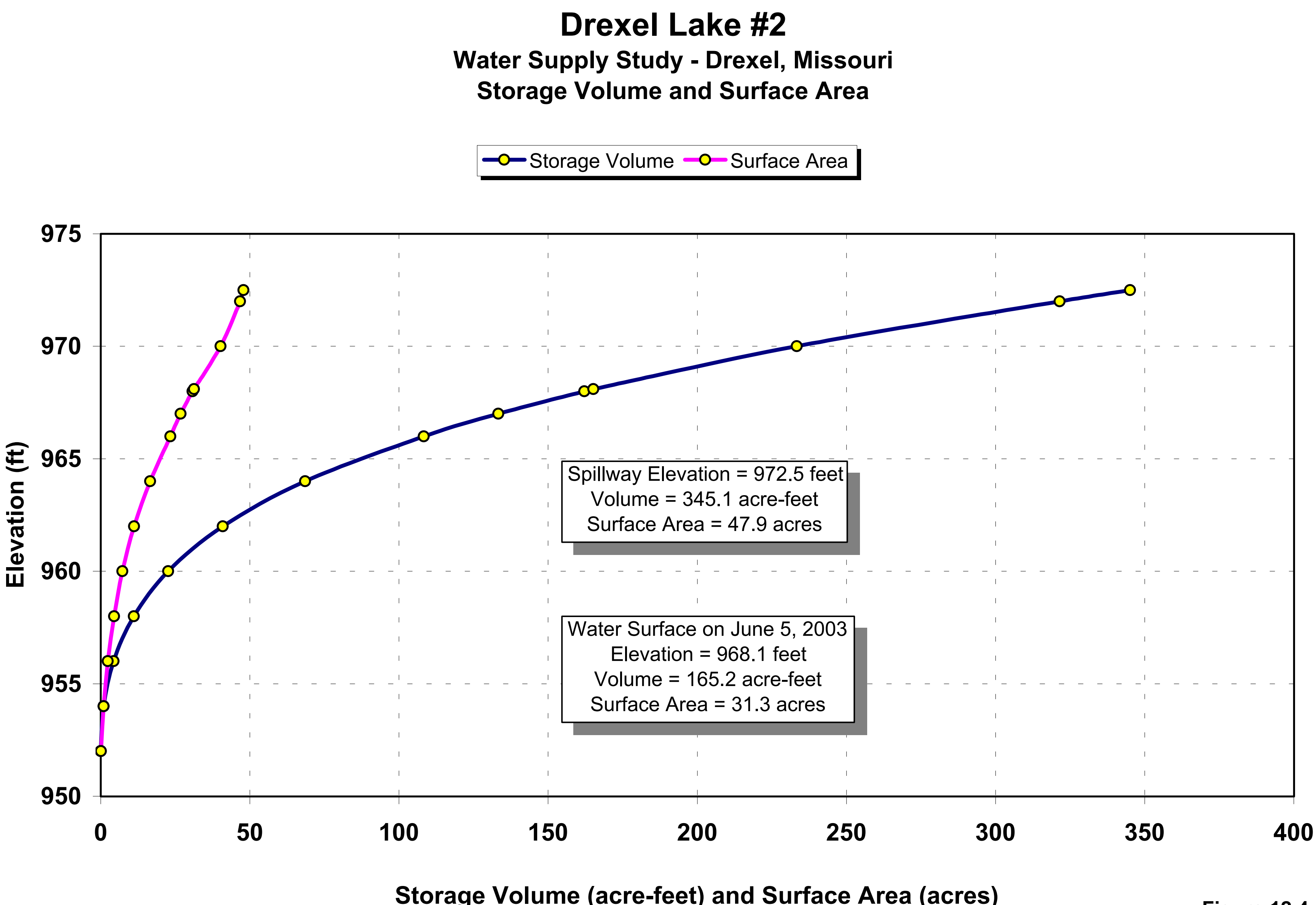

Drexel Lake #2
Water Supply Study - Drexel, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 972.5 feet
Volume = 345.1 acre-feet
Surface Area = 47.9 acres
Water Surface on June 5, 2003
Elevation = 968.1 feet
Volume = 165.2 acre-feet
Surface Area = 31.3 acres
Elevation (ft)
975
970
965
960
955
950
0
50
100
150
200
250
300
350
400
Storage Volume (acre-feet) and Surface Area (acres)

Figure 12.4

D.C. Rogers Reservoir
Water Supply Study – Fayette, Missouri
Drought Assessment Analysis

I. Overview

D.C. Rogers Reservoir is located in Howard County in central Missouri (figure 13.1). There are two reservoirs capable of supplying water to Fayette. D.C. Rogers Reservoir is located one mile west of the city of Fayette. Fayette Reservoir is located upstream of D.C. Rogers Reservoir and is the older water supply reservoir. Water can be released from the upper lake into D.C. Rogers Reservoir.

The D.C. Rogers Reservoir serves a population of approximately 2,888 with an estimated water demand of 0.361 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). Figure 13.2 illustrates Fayette's historical water use.

These reservoirs are on Adams Creek, a tributary to Bonne Femme Creek. The drainage area for the Fayette Lake is 1.96 square miles and the intervening area for D.C. Rogers Lake is 1.93 square miles for a total of 3.89 square miles.

D.C. Rogers Lake was surveyed March 19, 2007. The upper lake, Fayette Lake, was not surveyed, as a result it was necessary to estimate the storage volume. To do that the elevations and surface area were determined from a 7.5- minute USGS topographic map. The area below the spillway elevation was assumed to be a direct ratio of the D.C. Rogers Reservoir. Volume was then determined based on that area. During large rainfall events discharge through Fayette Reservoir's spillway was added to the inflow to D.C. Rogers Lake.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Two scenarios were studied. The first analyzed D.C. Rogers Lake by itself to analyze normal demand and optimum demand. Overflow from Fayette Lake was added to the inflow of D.C. Rogers Lake. The second scenario involved releasing water from Fayette Reservoir to D.C. Rogers Reservoir to meet normal demand. Figures 13.3.a and 13.3.b illustrate these results.

II. Drought Assessment Summary

Data reported, by the city, to the Department of Natural Resources data base "Missouri major water users" for the period 1989 through 2001 shows the city water needs of 0.494 million gallons per day (figure 13.3) was met by the D.C. Rogers Reservoir. This analysis shows that the drought of record is the 1950's. The city's demands could not be met with the D.C. Rogers Lake alone. In order to maintain a minimum of 500 acre-feet of water in the lake it was necessary to obtain a total of 1000 acre-feet from the upper Fayette Lake. In December 1954 it was necessary to release 40 acre-feet, in 1955 another 80 acre-feet was needed, 1956 needed 480 acre-feet, 1957 required 360 acre-feet and January 1958 needed 40 acre-feet for a total of 1000 acre feet. 175 Acre-feet remained in the upper

Fayette Lake. The lakes did not refill quickly because the drainage area size does not allow quick recharge. For this reason the period of analysis was extended to 1961.

III. RESOP model parameters

Terms in brackets (and bold print) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of D.C. Rogers Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on May 19, 2007. Surface area of the lake and associated storage volume capacities are illustrated in figures 13.4.a and 13.4.b.

D.C. Rogers and Fayette Reservoirs Physical Data

D.C. Rogers Reservoir				***Fayette Reservoir***		
Elevation (feet)	Area (acres)	Volume (ac-ft)		Assumed Elevation (feet)	Estimated Area (acres)	Volume (ac-ft)
667.0	0	0		703	0	0
668.0	5.6	3.6		705	5	9
670.0	12.8	23		707	10	23
672.0	26.1	62		709	13	47
674.0	35.9	124		711	18	78
676.0	47.4	207		713	23	118
678.0	61.0	315		715	28	169
680.0	75.5	451		717	35	232
682.0	93.1	620		719	40	312
684.0	106	819		721	45	391
686.0	121	1,050		723	52	544
688.0	138	1,310		725	58	696
690.0	155	1,600		727	63	717
692.0	169	1,920				
694.0	190	2,280				
695.2	201	2,520				
Lake Conditions on March 19, 2007 Elevation = 695.2 feet Spillway Elevation = 695.2 feet				Estimated Spillway Elevation = 727.0 feet		

[LIMITS]

D.C. Rogers Lake (Lower Lake)
Maximum storage…………………………………………………………...2,520 acre-feet
Minimum Pool storage…………………………………………………..……121 acre-feet
Drainage Basin Size……………………………………………….....1.93 square miles

Fayette Lake (Upper Lake)
Maximum Storage……………………………………………………..………717 acre-feet
Minimum Storage………………………………………………………………… 50 acre-feet
Drainage Basin Size…………………………………………………..……1.96 square miles

[GENERAL]

The record period of drought is in the 1950's. The analysis period used in this model is January 1951 and ended December 1961.

[SEEPAGE]

Seepage from D.C. Rogers Lake is estimated to be 3.5 inches per month when at or full capacity and approaches 0.0 inches when the reservoir is near empty. Seepage from Fayette Reservoir was estimated at 1 inch per month when at full capacity and approaches 0.0 inches per month when the reservoir is near empty. Seepage from the Fayette Reservoir will accumulate in D.C. Rogers Reservoir. The reservoirs are bound by an earthen dams composed of compacted clay-rich materials-seepage through the dams are considered minimal.

[RAINFALL]

Average precipitation in Fayette was 38.5 inches for 1970 through 2000. Precipitation values for the drought of record were obtained from Fayette Missouri. The most severe drought occurred between 1953 and 1957 with annual precipitation values of 23.27, 32.59, 38.77, 23.76 and 37.31 inches.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected at the Petite Saline Creek gauge near Boonville. When runoff did not appear reasonable compared to rainfall, it was necessary to examine daily rainfall values for that month. Antecedent moisture was estimated for each rainfall event and adjustments to NRC'S runoff curve number were made to arrive at direct runoff for each storm. (See Appendix A for additional information).

[EVAP.]

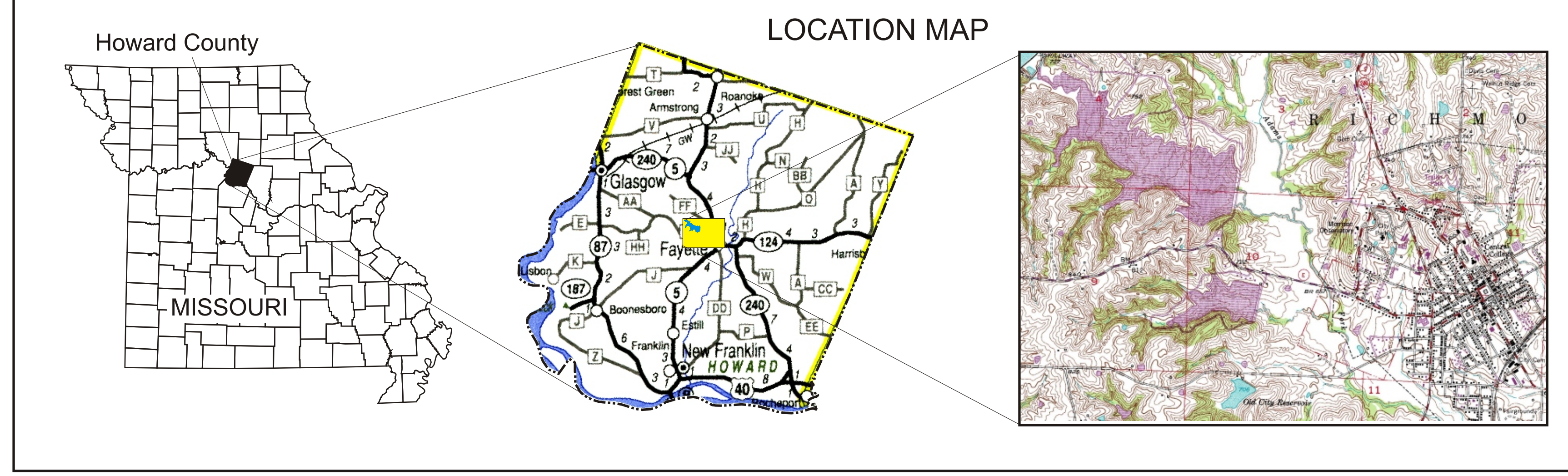
Pan evaporation data from Lakeside gauging station (near the Lake of the Ozarks) was used to estimate water loss from D.C. Rogers Reservoir due to evaporation. This data was supplemented and compared with evaporation stations at New Franklin, and Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation values.

[DEMAND]

Water demand was obtained from records reported by the city records to Missouri Department of Natural Resources “Major Water Users Data Base”. Their water use has been steadily declining. In 1989 they reported using 0.50 million gallons per day and in 2001 they reported 0.36 million gallons per day. For this evaluation a mid-point demand of 0.42 million gallons per day was assumed. During this 13 years of data, demand steadily decreased by average of 11,700 gallons per day.

[OTHER]

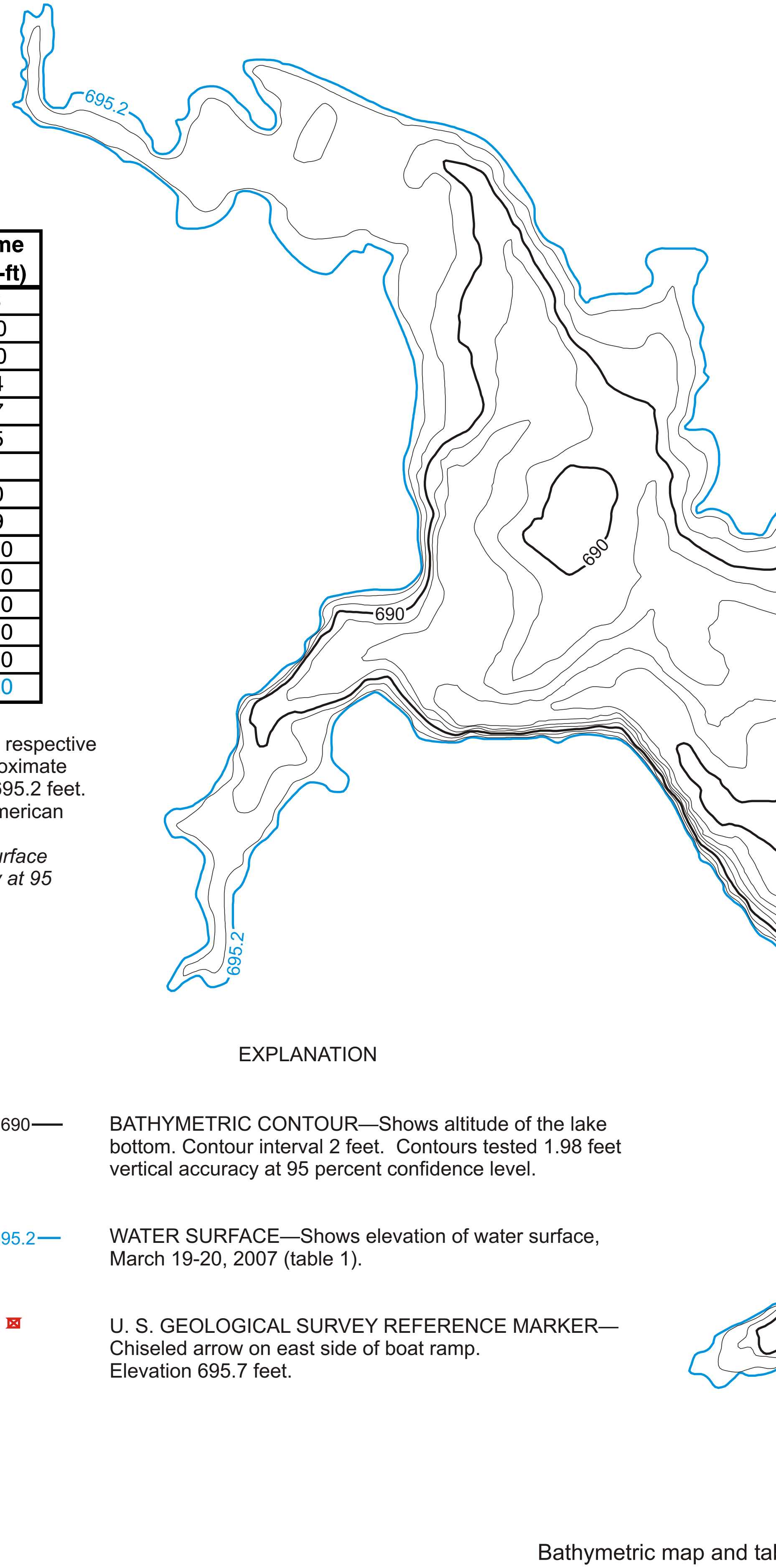
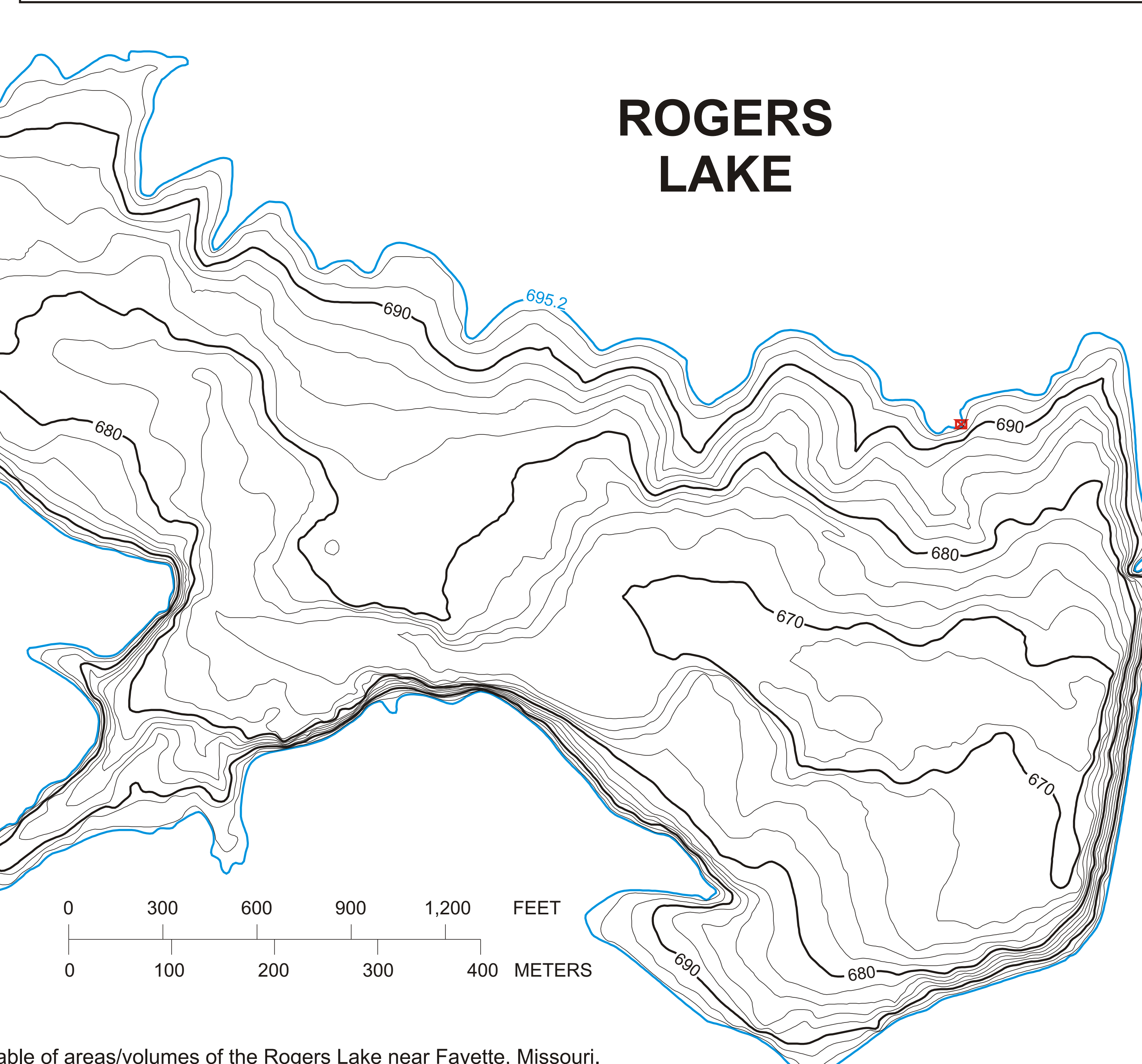
Other is the gain or loss from sources other than the above control words. For the months that water was needed to keep D.C. Rogers Reservoir at or above 500 acre-feet of storage, water was released from Fayette Reservoir and added to D.C. Rogers Reservoir.



ROGERS LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
668.0	5.6	3.6
670.0	12.8	23.0
672.0	26.1	62.0
674.0	35.9	124
676.0	47.4	207
678.0	61.0	315
680.0	75.5	451
682.0	93.1	620
684.0	106	819
686.0	121	1,050
688.0	138	1,310
690.0	155	1,600
692.0	169	1,920
694.0	190	2,280
695.2	201	2,520

Table 13.1 Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 695.2 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.29 feet vertical accuracy at 95 percent confidence level.

EXPLANATION

—690— BATHYMETRIC CONTOUR—Shows altitude of the lake bottom. Contour interval 2 feet. Contours tested 1.98 feet vertical accuracy at 95 percent confidence level.

—695.2— WATER SURFACE—Shows elevation of water surface, March 19-20, 2007 (table 1).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on east side of boat ramp. Elevation 695.7 feet.

USGS
science for a changing world

Bathymetric map and table of areas/volumes of the Rogers Lake near Fayette, Missouri.

In cooperation with Missouri Department of Natural Resources

Figure 13.1

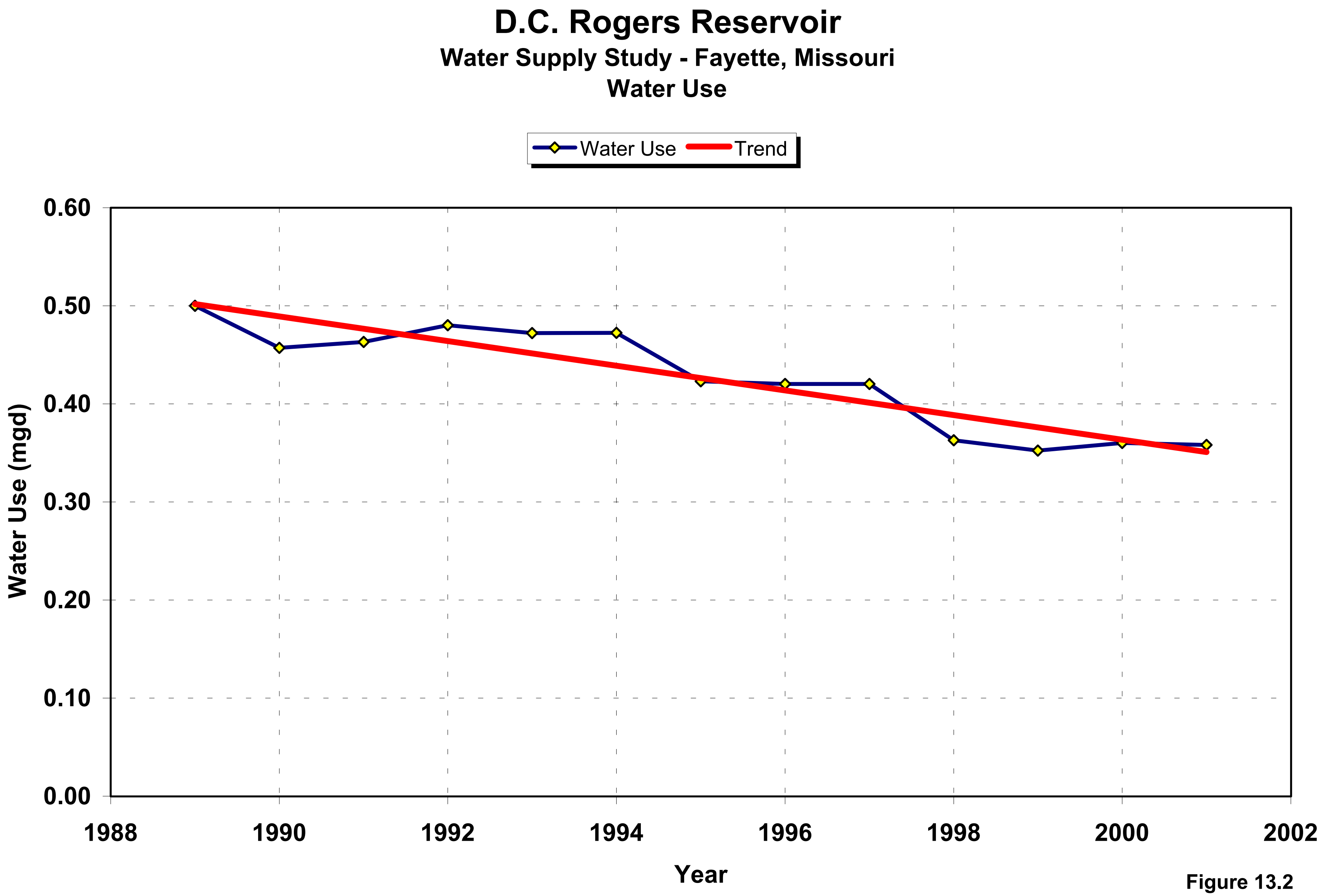

D.C. Rogers Reservoir
Water Supply Study - Fayette, Missouri
Water Use
Water Use
Trend
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Water Use (mgd)
1988
1990
1992
1994
1996
1998
2000
2002
Year

Figure 13.2

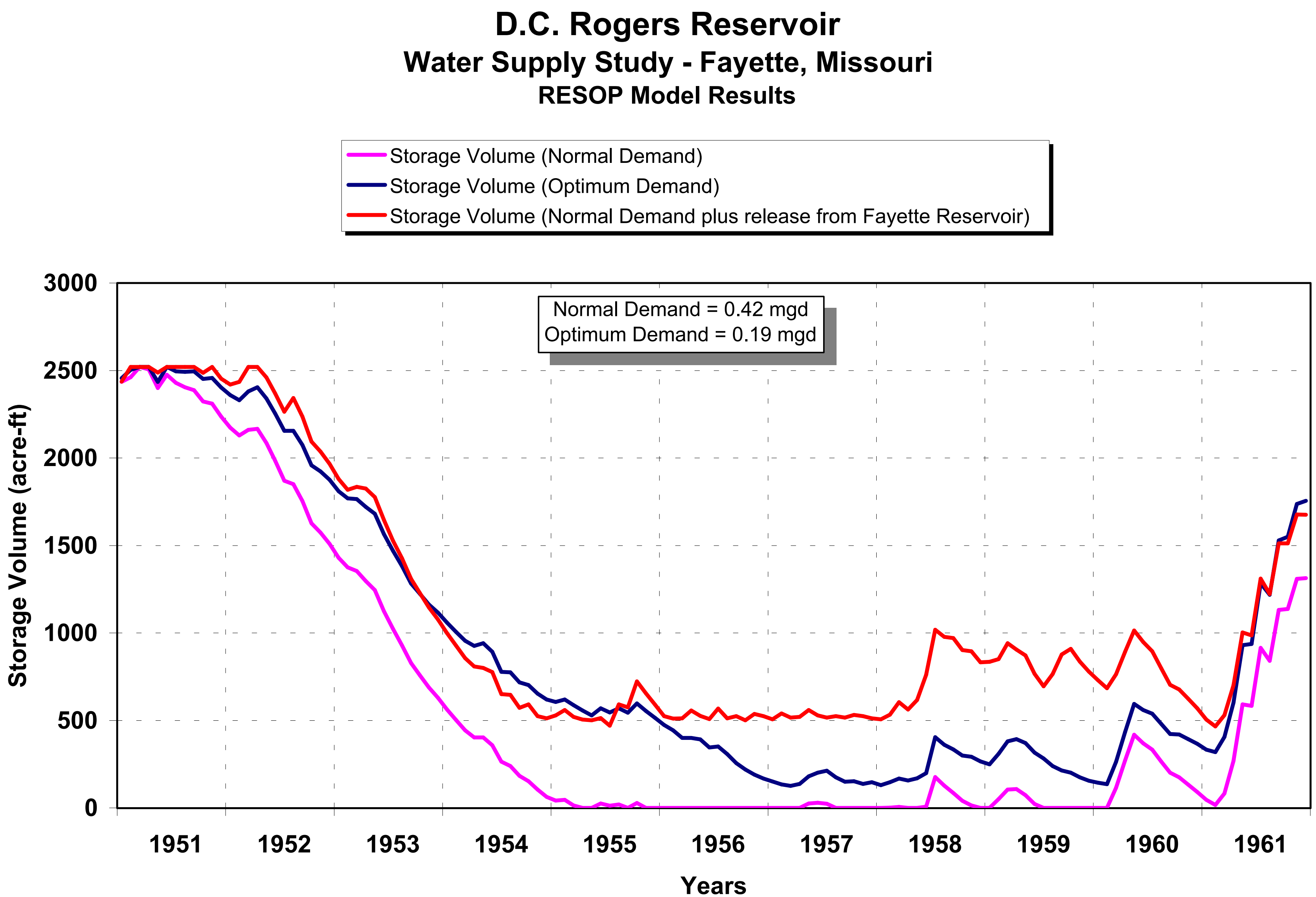

D.C. Rogers Reservoir
Water Supply Study - Fayette, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Storage Volume (Normal Demand plus release from Fayette Reservoir)
Normal Demand = 0.42 mgd
Optimum Demand = 0.19 mgd
Storage Volume (acre-ft)
3000
2500
2000
1500
1000
500
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
Years

Figure 13.3.a

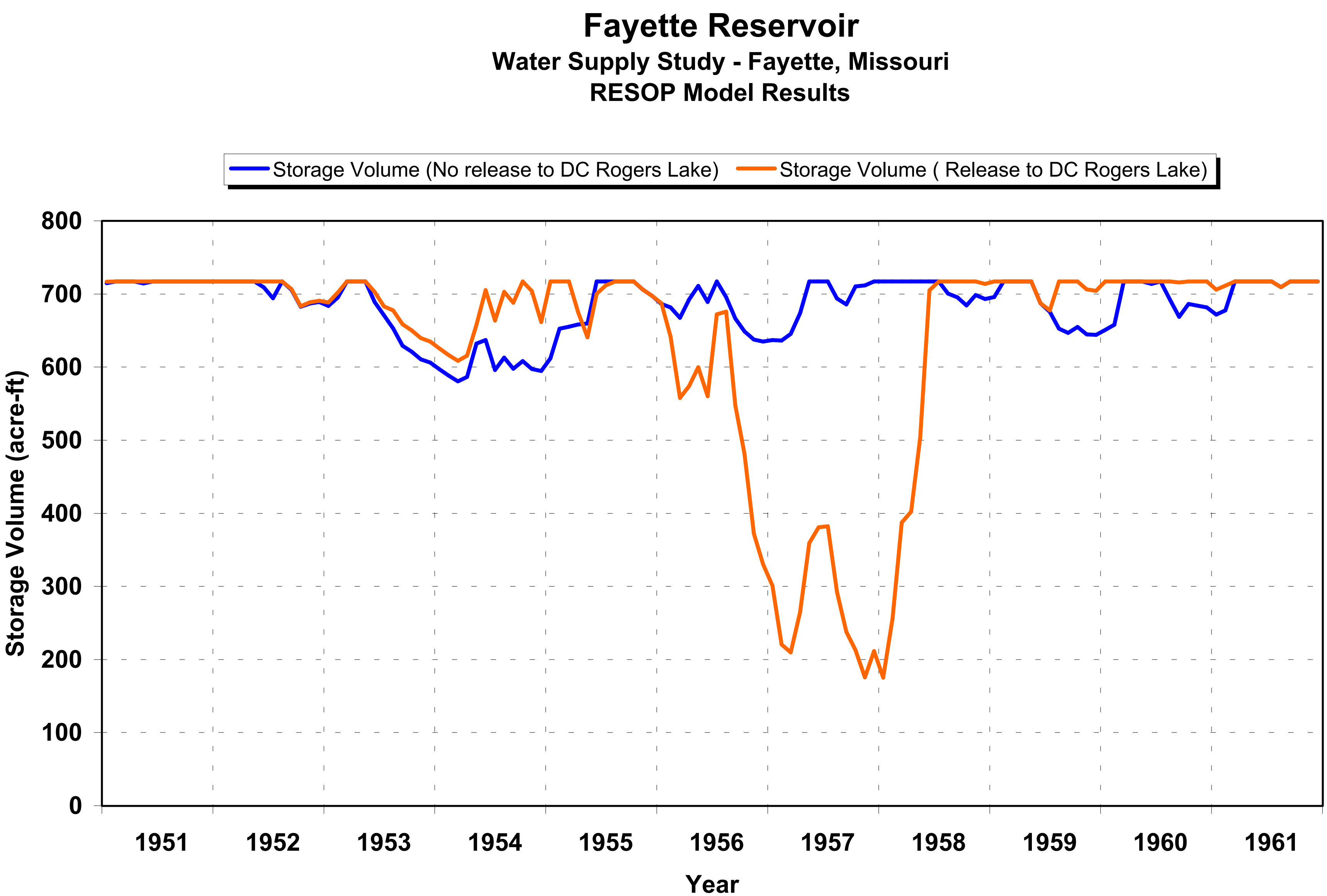

Fayette Reservoir
Water Supply Study - Fayette, Missouri
RESOP Model Results
Storage Volume (No release to DC Rogers Lake)
Storage Volume (Release to DC Rogers Lake)
Storage Volume (acre-ft)
0
100
200
300
400
500
600
700
800
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
Year

Figure 13.3.b

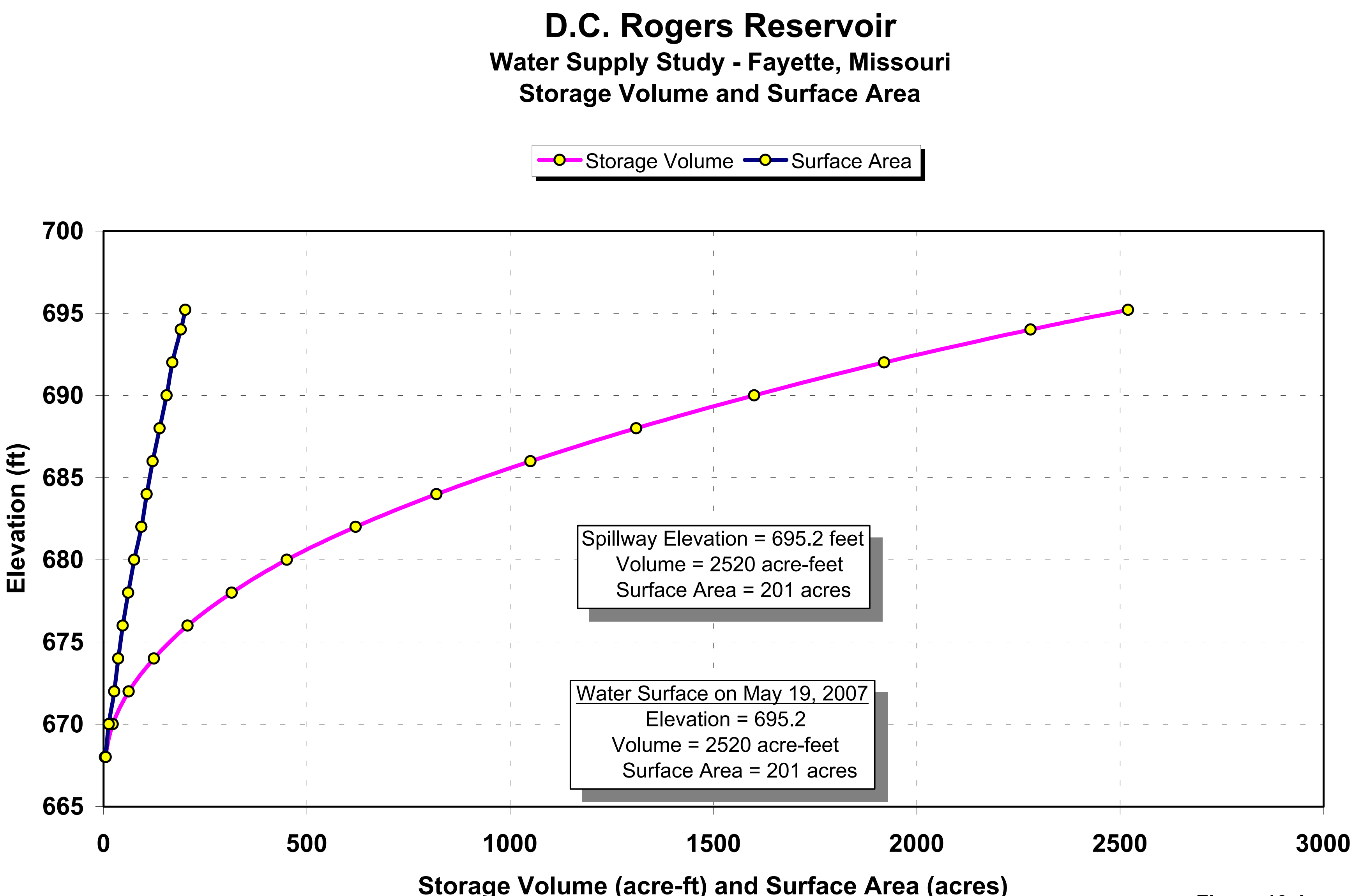

D.C. Rogers Reservoir
Water Supply Study - Fayette, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 695.2 feet
Volume = 2520 acre-feet
Surface Area = 201 acres
Water Surface on May 19, 2007
Elevation = 695.2
Volume = 2520 acre-feet
Surface Area = 201 acres
Elevation (ft)
700
695
690
685
680
675
670
665
0
500
1000
1500
2000
2500
3000
Storage Volume (acre-ft) and Surface Area (acres)

Figure 13.4.a

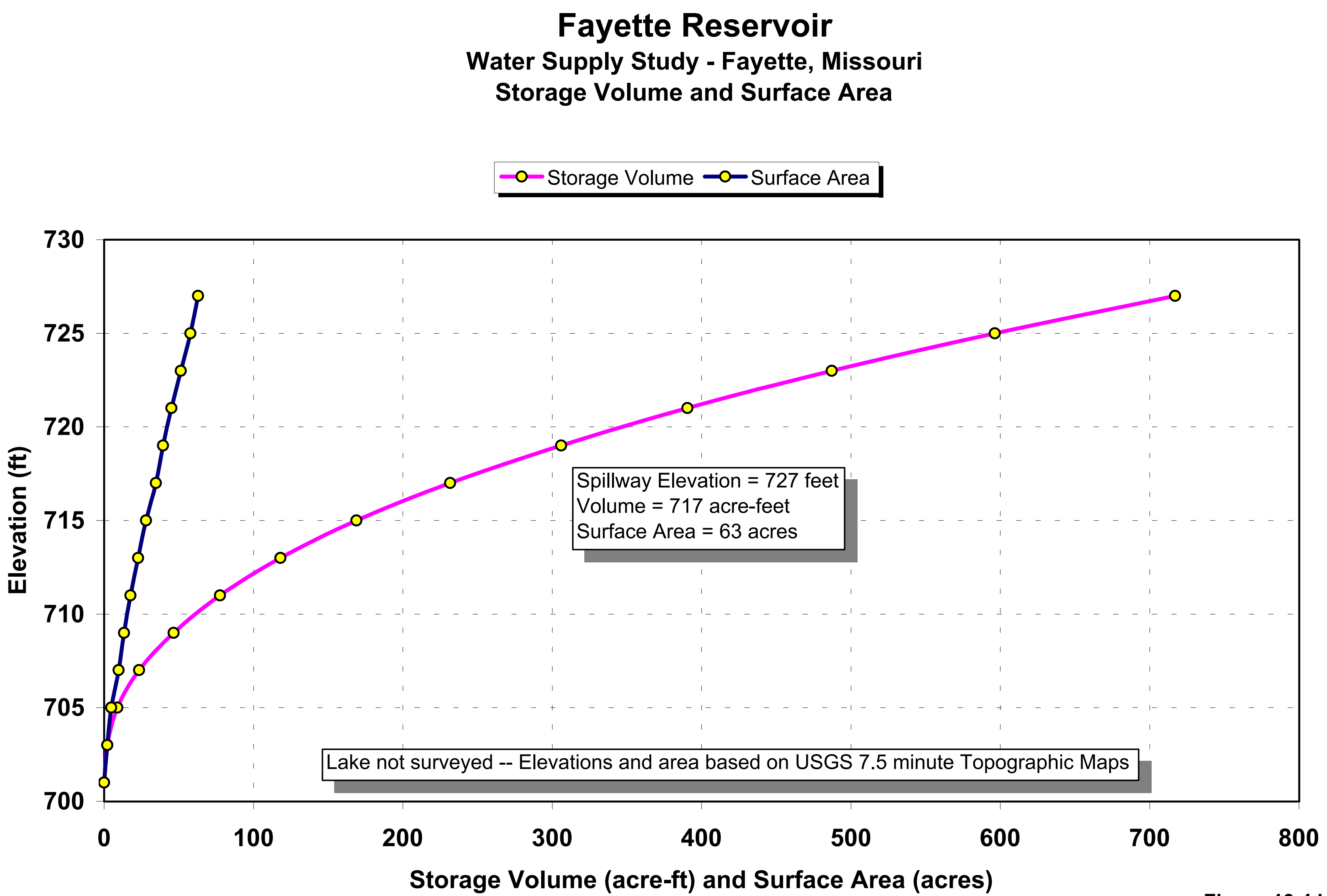

Fayette Reservoir
Water Supply Study - Fayette, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
730
725
720
715
710
705
700
Elevation (ft)
Spillway Elevation = 727 feet
Volume = 717 acre-feet
Surface Area = 63 acres
Lake not surveyed -- Elevations and area based on USGS 7.5 minute Topographic Maps
0
100
200
300
400
500
600
700
800
Storage Volume (acre-ft) and Surface Area (acres)

Figure 13.4.b

Garden City Reservoirs #1 (Old) and #2 (New)
Water Supply Study – Garden City, Missouri
Drought Assessment Analysis

I. Overview

Two reservoirs make up the reservoir system that provides the water supply for Garden City. The Garden City Reservoir #2 (figure 14.1.a) is located 2.5 miles south south east of Garden City. Reservoir #1 (figure 14.1.b) is located one mile east of Garden City. Garden City is located in southwestern Cass County, Missouri, and approximately 10 miles southeast of Harrisonville. Prior to 1994 Reservoir #1 was the only source of drinking water for Garden City. The population served by the Garden City reservoir system is approximately 1,364 with an average consumption of 0.138 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). Historical water demand on each of the Garden City Reservoirs is illustrated in figure 14.2.

Garden City's Lake #2 was constructed 1992 and the city began using the water in 1994. This lake is located 2.5 miles south south east of Garden City. Its drainage area is 1.70 square miles. Lake #1 is located 1 mile east of Garden City and has a drainage area of 0.67 square miles. The operating plan is to use whichever lake has a supply that meets their needs.

Demand for evaluation of Garden Cities water supply were determined from Department of Natural Resources, major water users database where the old lake is listed as Lake #1 and the new lake as Lake #2. In year 2000 Lake #1 provided 20,311,090 gallon of water or 55,646 gallons per day and Lake #2 provided 29,889,810 gallons or 81,890 gallons per day. The total was 50,200,900 gallons for an average daily use of 137,540 gallons per day. For evaluation of Garden City's water supply, these demands were used.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Year 2000 demand of 0.138 million gallons per day was distribute between the two reservoirs assuming 60 percent (0.082 million gallons per day) of the total demand would be assigned to Reservoir #2 (New) and 40 percent (0.056 million gallons per day) assigned to Reservoir #1 (Old). Combined optimum demand is 0.251 million gallons per day.

II. Drought Assessment Summary

Reservoir #2 RESOP model assumes 'Normal' demand to be 82,000 gallons per day and the resulting 'Optimum' yield from the lake is 182,000 gallons per day. Figure 14.3.a illustrates these relationships. Expectations would have 250 acre-feet of water remaining in the reservoir in July 1954.

Reservoir #1 model assumes 'Normal' demand to be an average of 56,000 gallons per day with 35 acre-feet of water remaining in the reservoir in July 1954. The 'Optimum' yield from the lake is 69,000 gallons per day. Figure 14.3.b illustrates these relationships.

III. RESOP Model Parameters

Terms in brackets refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Garden City Reservoirs conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on April 5 and 6, 2004. These relationships are illustrated in figure 14.4.a for Lake #2 and figure 14.4.b for Lake #1.

Garden City Reservoirs #1 and #2 Lakes (New and Old Lakes)

Garden City #2 (New) Reservoir				***Garden City #1 (Old) Reservoir***		
Elevation (feet)	Area (acres)	Volume (acre-feet)		Elevation (feet)	Area (acres)	Volume (acre-feet)
842.0	0.3	0.2		878.0	0.15	0.02
844.0	2.5	2.9		880.0	1.7	1.7
846.0	5.0	10.5		882.0	5.1	7.8
848.0	7.9	23.4		884.0	10.2	24.4
850.0	12.4	43.7		886.0	13.6	48.2
852.0	16.2	72.6		888.0	19.3	81.4
854.0	20.1	108.8		890.0	23.4	124.7
856.0	23.8	152.7		892.0	26.1	174.3
858.0	27.7	203.7		892.1	27.1	177.0
860.0	33.7	264.7		893.0	30.4	202.9
862.0	39.3	337.7		894.0	33.5	234.9
862.4	40.5	353.7		895.0	36.8	270.0
864.0	48.8	426.1				
864.3	49.9	440.9				
866.0	57.4	523.0				
867.2	63.0	604.2				
Spillway Elevation = 862.4 feet Lake Conditions on April 5, 2004 Elevation = 862.4 feet Emergency Spillway Elevation = 864.3 feet Top of Dam Elevation = 867.2 feet				Spillway Elevation = 892.1 feet Lake Conditions on April 6, 2004 Elevation = 892.0 feet Emergency Spillway Elevation = 893.0 feet Top of Dam Elevation = 895.0 feet		

[LIMITS]

Garden City #2 (New) Lake
Maximum storage ....440.9 acre-feet
Minimum storage ....50 acre-feet
Drainage basin size .... 1.70 square miles

Garden City #1 (Old) Lake
Maximum storage ....177.0 acre-feet
Minimum storage ....10 acre-feet
Drainage basin size .... 0.67 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity for both lakes.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Garden Cities Lakes One and Two is estimated to be approximately 1.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Rainfall data came from the Harrisonville, Missouri precipitation gage for the evaluation period 1951 through 1959.

Average precipitation in Garden City was 42.05 inches between 1970 and 2000. Precipitation values for the drought of record were obtained from Harrisonville, Missouri (approximately 16 miles northeast of Garden City. The most severe drought occurred between 1953 and 1957 with annual precipitation values in Harrisonville of 28.8 inches, 35.7 inches, 28.4 inches, 21.3 inches, and 37.5 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Little Blue River stream gauge near Lake City. Another gauge on Cedar Creek near pleasant View, Missouri was analyzed for comparison. Comparison of the total runoff from the two gauges resulted in favorable results. Little Blue River runoff volume was chosen to represent Garden Cities Lakes where soils, vegetation and topography was more representative of Garden Cities Reservoirs drainage basins. When this regional runoff value is inconsistent with precipitation values recorded for Garden City, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service’s (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information

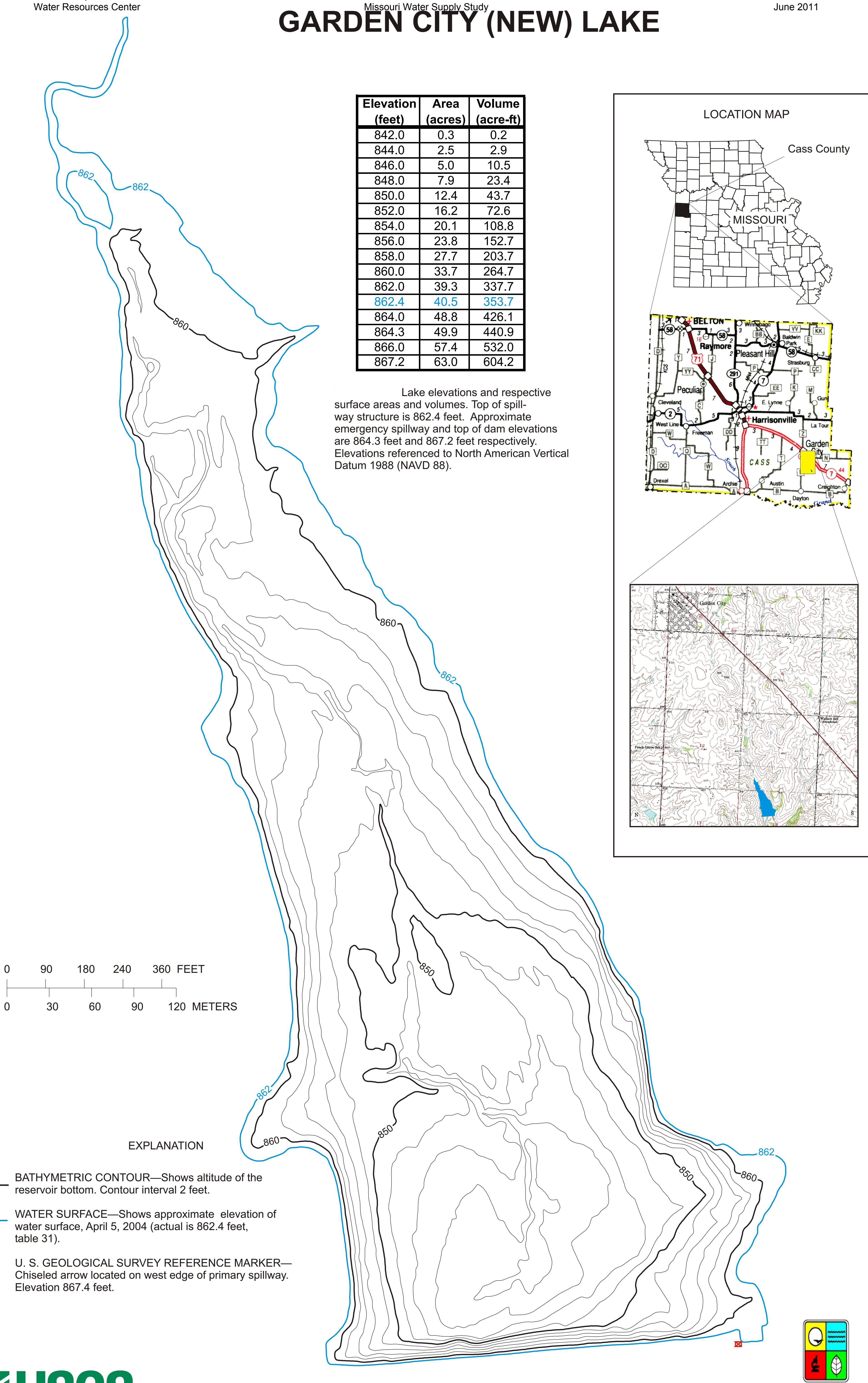
[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Garden City Reservoirs due to evaporation. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

Values for water usage by Garden City are illustrated in figure 14.2. Year 2000 demand was used to represent demand from each lake. Lake #2 normal demand was 82,000 gallons per day and Lake #1 demand was 56,000 gallons per day. Water demand was obtained from records reported by the city to Missouri Department of Natural Resources “Major Water Users Data Base”. Their water use has been increasing at a rate of 750 gallons per day each year.

GARDEN CITY (NEW) LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
842.0	0.3	0.2
844.0	2.5	2.9
846.0	5.0	10.5
848.0	7.9	23.4
850.0	12.4	43.7
852.0	16.2	72.6
854.0	20.1	108.8
856.0	23.8	152.7
858.0	27.7	203.7
860.0	33.7	264.7
862.0	39.3	337.7
862.4	40.5	353.7
864.0	48.8	426.1
864.3	49.9	440.9
866.0	57.4	532.0
867.2	63.0	604.2

Lake elevations and respective surface areas and volumes. Top of spillway structure is 862.4 feet. Approximate emergency spillway and top of dam elevations are 864.3 feet and 867.2 feet respectively. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).

EXPLANATION

—860— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

—862— WATER SURFACE—Shows approximate elevation of water surface, April 5, 2004 (actual is 862.4 feet, table 31).

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west edge of primary spillway. Elevation 867.4 feet.

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Bathymetric map and table of areas/volumes of the Garden City (New) Lake near Garden City, Missouri.

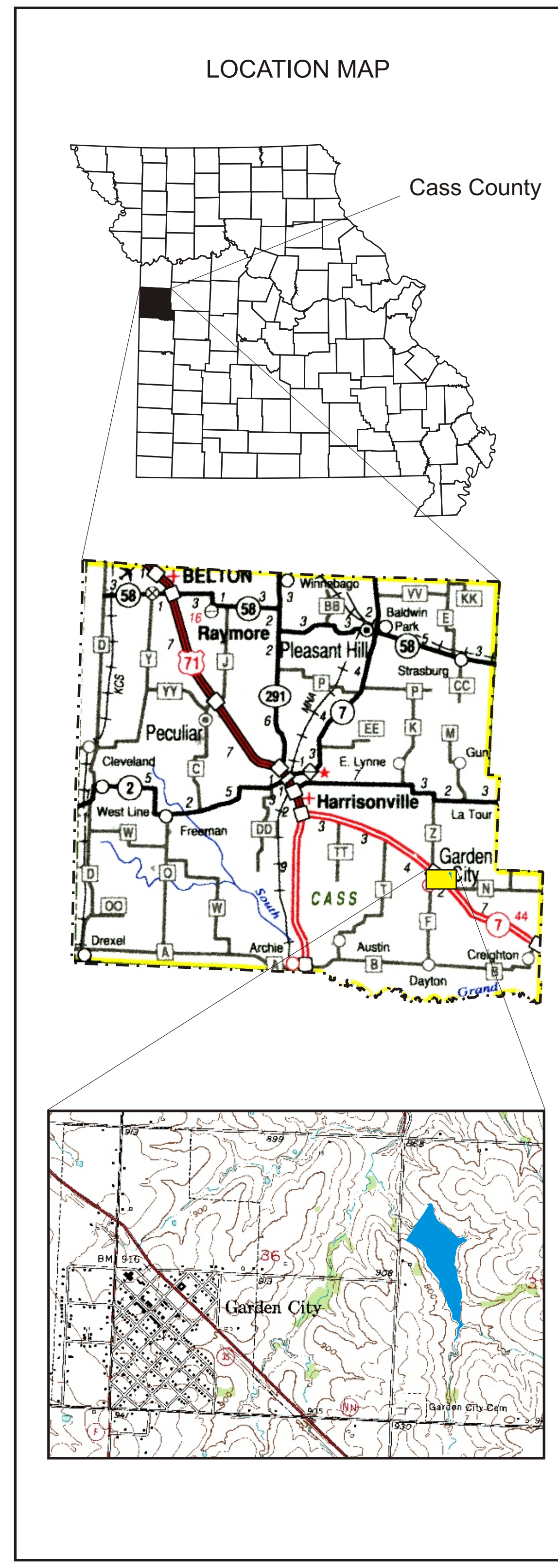
In cooperation with Missouri Department of Natural Resources

Figure 14.1.a

Missouri Department of Natural Resources
Water Resources Center

June 2011

GARDEN CITY LAKE



EXPLANATION

—890— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

—892— WATER SURFACE—Shows elevation of water surface, April 6, 2004.

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on north east corner of spillway. Elevation 893.52 feet.

Elevation (feet)	Area (acres)	Volume (acre-ft)
878.0	0.15	0.02
880.0	1.7	1.7
882.0	5.1	7.8
884.0	10.2	24.4
886.0	13.6	48.2
888.0	19.3	81.4
890.0	23.4	124.7
892.0	26.1	174.3
892.1	27.1	177.0
893.0	30.4	202.9
894.0	33.5	234.9
895.0	36.8	270.0

Table 14.1.b Lake elevations and respective surface areas and volumes. Top of spillway structure is 892.1 feet. Approximate emergency spillway and top of dam elevations are 893.0 and 895.0 feet respectively. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).

Figure 14.1.b

USGS science for a changing world

Figure 14.1.b Bathymetric map and table of areas/volumes of the Garden City Lake near Garden City, Missouri.

In cooperation with Missouri Department of Natural Resources

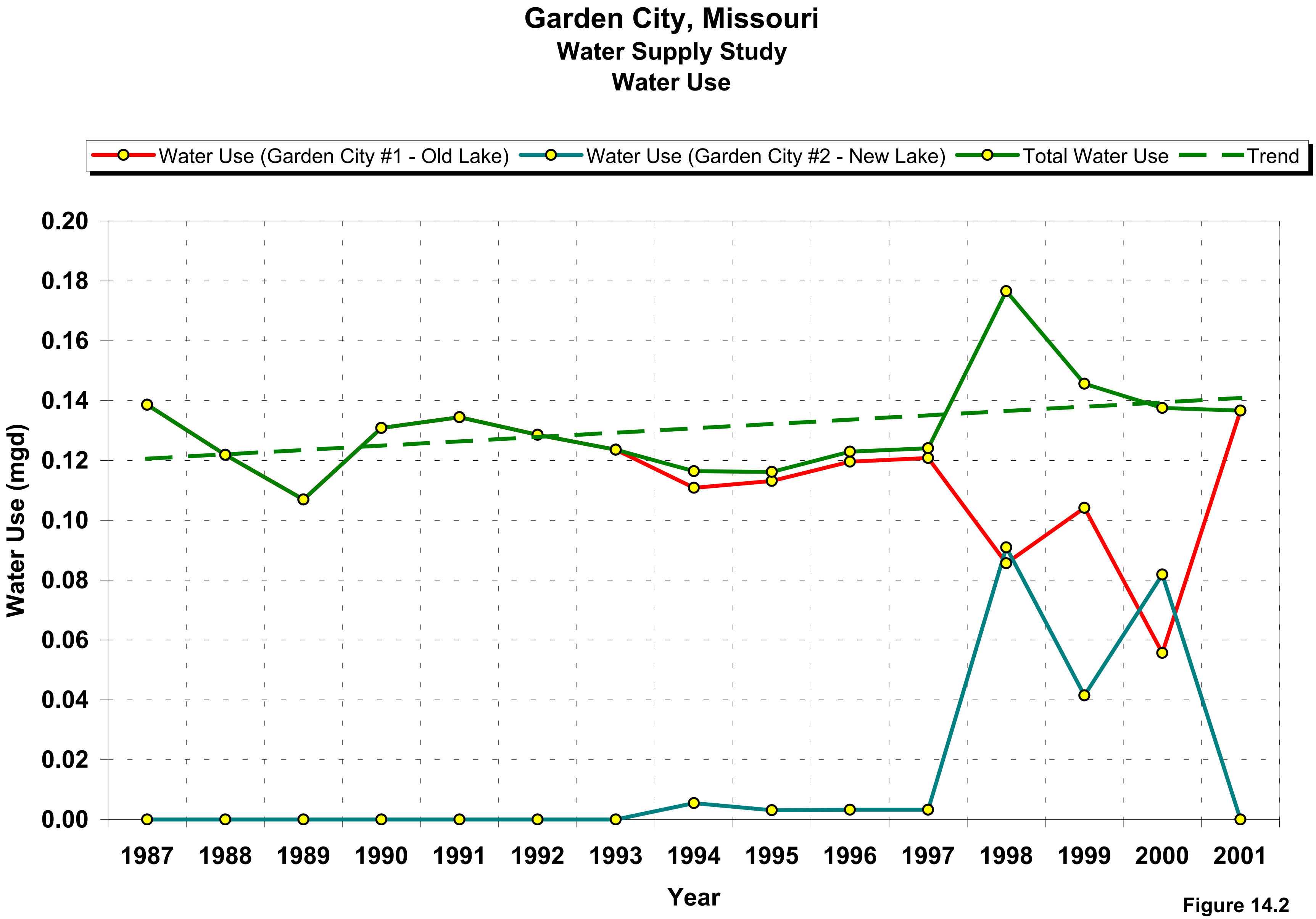

Garden City, Missouri
Water Supply Study
Water Use
Water Use (Garden City #1 - Old Lake)
Water Use (Garden City #2 - New Lake)
Total Water Use
Trend
Water Use (mgd)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 14.2

Garden City Lake Number 2 (New Lake)
Water Supply Study - Garden City, Missouri
RESOP Model Results

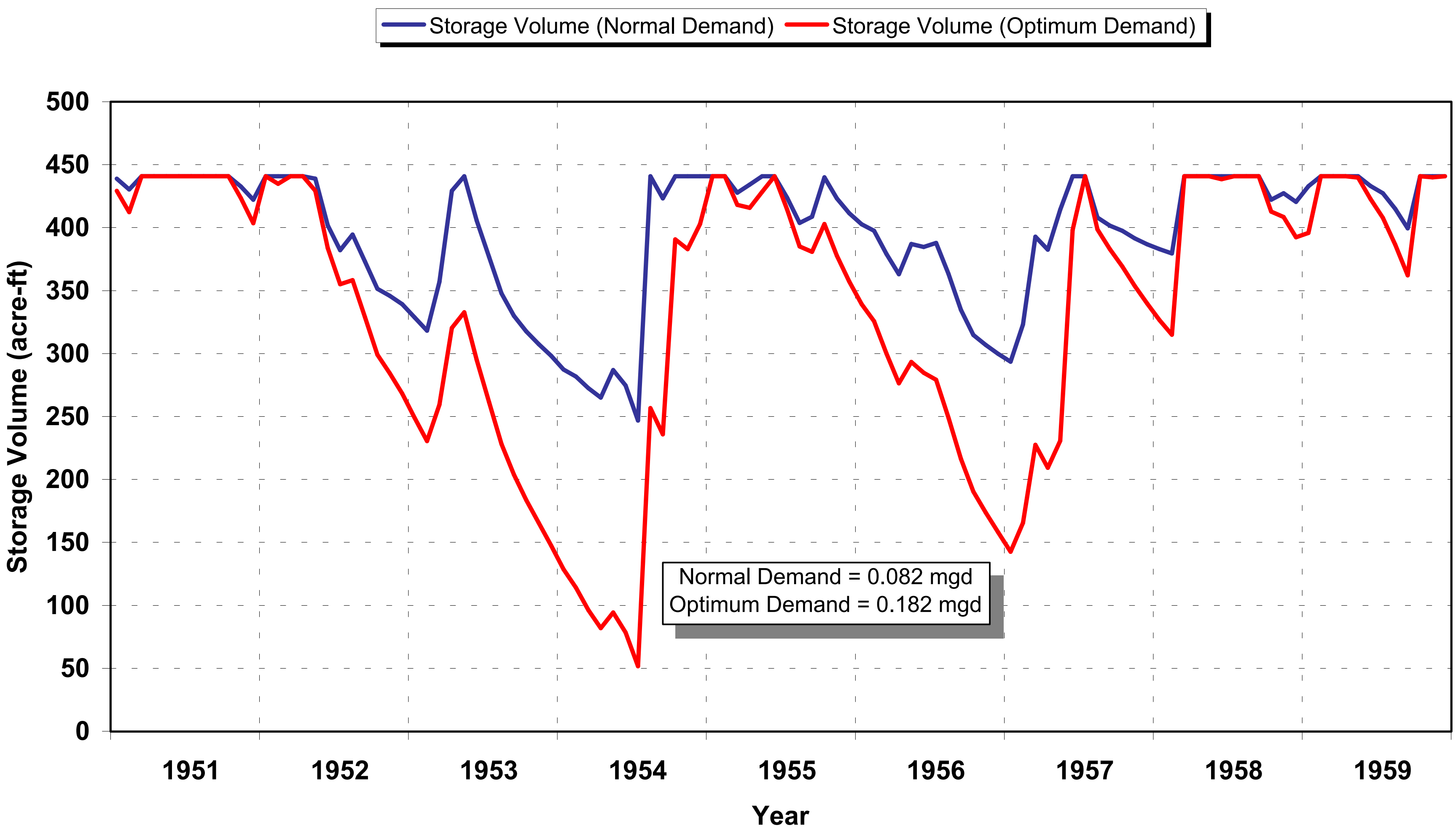


Figure 14.3.a

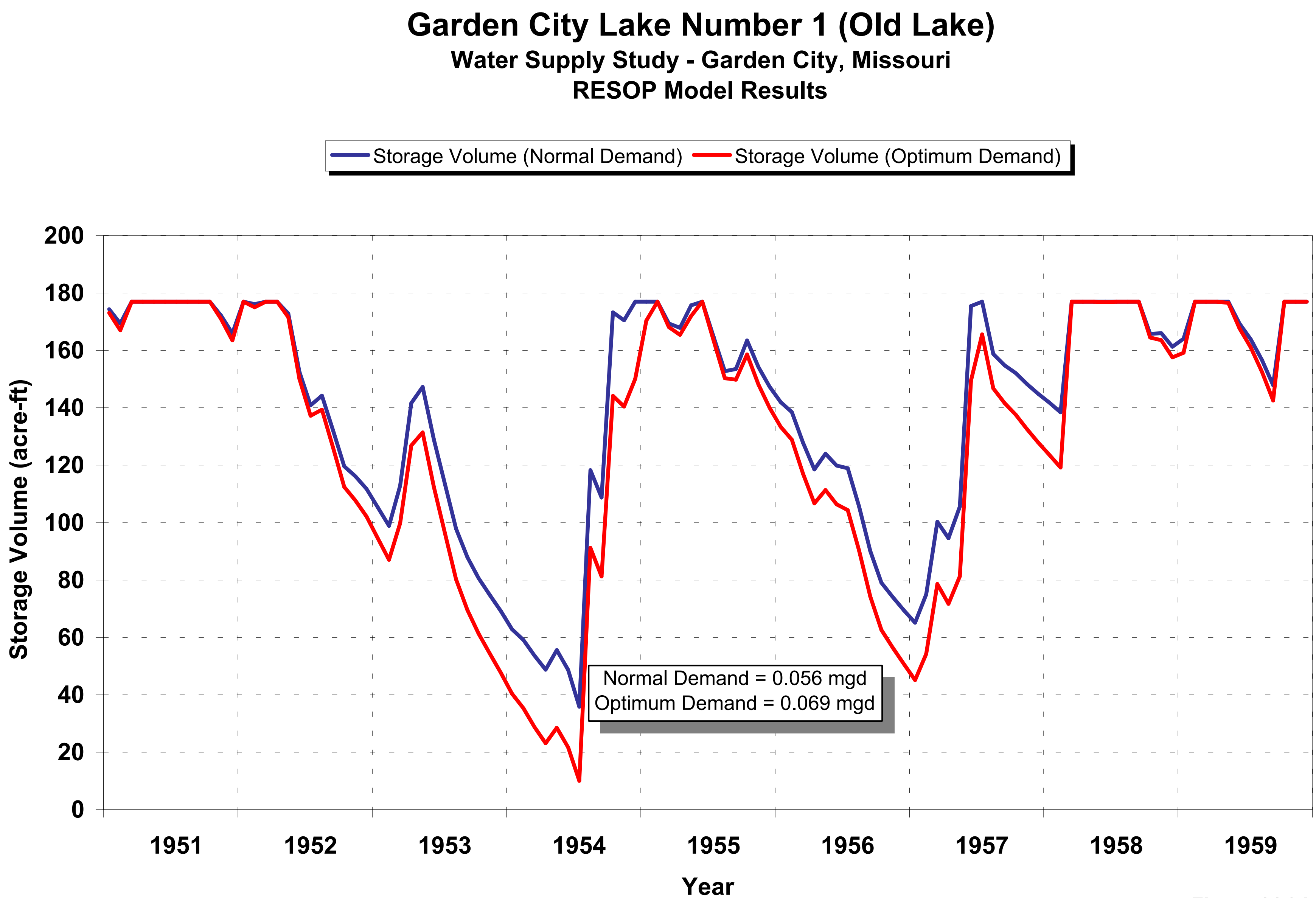

Garden City Lake Number 1 (Old Lake)
Water Supply Study - Garden City, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
200
180
160
140
120
100
80
60
40
20
0
Storage Volume (acre-ft)
Normal Demand = 0.056 mgd
Optimum Demand = 0.069 mgd
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 14.3.b

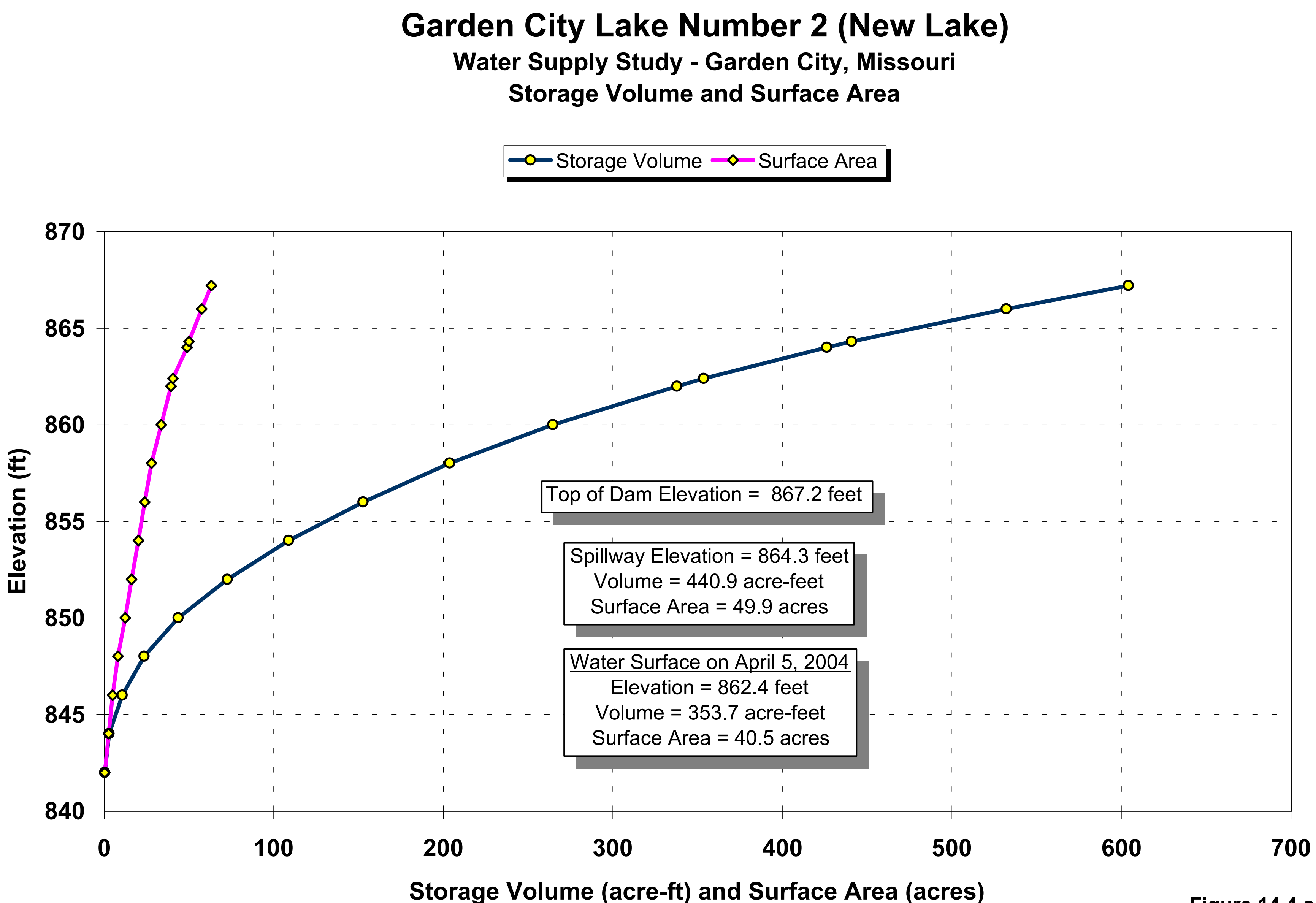

Garden City Lake Number 2 (New Lake)
Water Supply Study - Garden City, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Elevation (ft)
870
865
860
855
850
845
840
0
100
200
300
400
500
600
700
Storage Volume (acre-ft) and Surface Area (acres)
Top of Dam Elevation = 867.2 feet
Spillway Elevation = 864.3 feet
Volume = 440.9 acre-feet
Surface Area = 49.9 acres
Water Surface on April 5, 2004
Elevation = 862.4 feet
Volume = 353.7 acre-feet
Surface Area = 40.5 acres

Figure 14.4.a

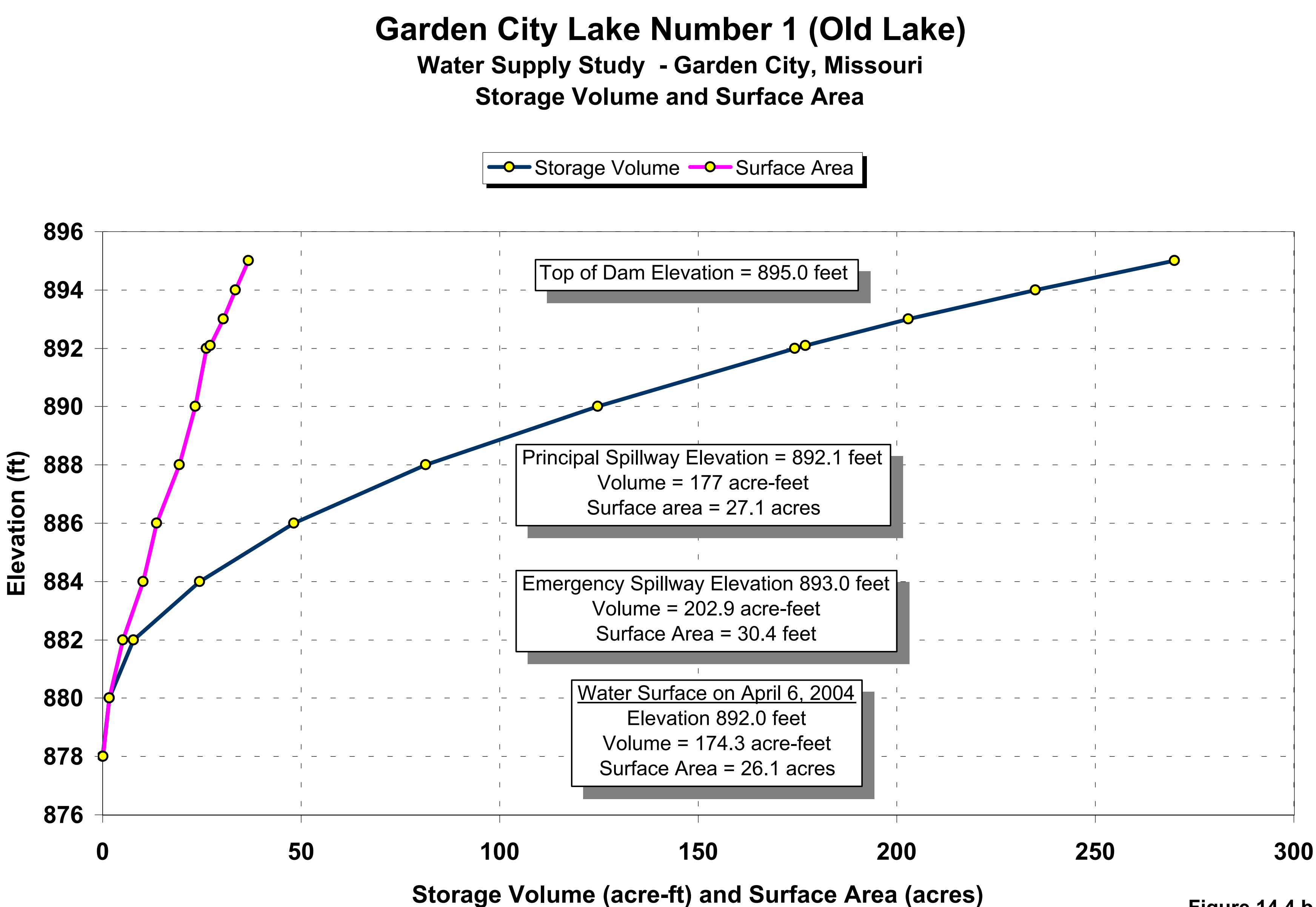

Garden City Lake Number 1 (Old Lake)
Water Supply Study - Garden City, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Top of Dam Elevation = 895.0 feet
Principal Spillway Elevation = 892.1 feet
Volume = 177 acre-feet
Surface area = 27.1 acres
Emergency Spillway Elevation 893.0 feet
Volume = 202.9 acre-feet
Surface Area = 30.4 feet
Water Surface on April 6, 2004
Elevation 892.0 feet
Volume = 174.3 acre-feet
Surface Area = 26.1 acres
Elevation (ft)
896
894
892
890
888
886
884
882
880
878
876
0
50
100
150
200
250
300
Storage Volume (acre-ft) and Surface Area (acres)

Figure 14.4.b

Green City Lake
Water Supply Study – Green City, Missouri
Drought Assessment Analysis

Green City Reservoir (figure 15.1) is located in the Green Hills Region of Northeast Missouri in Sullivan County. Green City is a rural community serving the agricultural necessities of the surrounding rural residents. Green City Reservoir has been the source of water supply for Green City, Greencastle and Sullivan Country rural water district. The Green City Reservoir serves a population of approximately 671 with an estimated water demand of 0.200 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). Historic water use is displayed in figure 15.2. The Green City Reservoir also supplies a portion of water needs to Green Castle. The existing Green City Reservoir was built in 1974 having a drainage area of approximately 871 acres. There are two large private ponds located in this watershed with the total drainage area with 72 acres. The two ponds result in a reduction of the watershed drainage area to the Green City Reservoir of 8.2 percent. The effective drainage area for Green City Reservoir is about 800 acres. Over flow from these two ponds was not added as inflow to the Green City Reservoir because the pond spillage occurs during times of excessive rainfall, when Green City Reservoir is also spilling through the spillway.

There are two spillways for the Green City Reservoir. The drop inlet spillway crest is at elevation 1000 feet and the emergency spillway crest is at 1004 feet. The top of the dam is at 1011 feet creating a dam height of about 30 feet.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Normal demand for the long-term average water use of 182,500 gallons per day was analyzed along with the optimum yield (figure 15.3.a). The reservoir storage upper limit is 438 acre-feet, the principal spillway elevation is 438 acre-feet. The lower limit for the first run is set to 6.52 acre-feet, which is at the water intake level. An additional analysis was then made to set the lower limit at 50 acre-feet, which is an estimate of useable water. The 50 acre-feet lower limit reduced the optimum demand from 148,600 gallons per day to 134,880 gallons per day.

Water shortage during the drought of 1999 and 2000 necessitated the next analyses. The demand of 182,500 gallons per day was reduced to 90,000 gallons per day for the period 1955 through 1959 by transferring the demand from the rural water districts to other sources of water. Normal and optimum demand analyses were made beginning at principal spillway elevation and the lower limit was 50 acre-feet. An additional normal demand was analyzed beginning at 100 acre-feet of storage. The demand of 90,000 gallons per day was determined to be attainable (figure 15.3.b).

II. Drought Assessment Summary

The Green City Reservoir is at risk of not meeting the community’s demand for water during times of drought without additional sources of water. The 1999 demand on the reservoir was approximately 183,000 gallons per day, and when this demand value is applied to the reservoir during the drought of record in the 1950’s, water deficits would have occurred between May 1956 and June 1958. The estimated optimum yield from Garden City Reservoir is 134,880 gallons per day without additional water sources (figure 15.3.a).

Additional analysis of the lake was made to show conditions at the time of the drought period beginning in 1998. The 1950's climate conditions were used to evaluate projected shortages. The rural water districts were transferred to another source of water supply to extend the duration of the existing water supply. With only Green City using the water, the reservoir would have enough to survive the 1950's drought (figure 15.3.b).

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Green City Reservoir conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources. Surface area of the lake and associated storage volume capacities are illustrated in figure 15.4.

Green City Reservoir Physical Data

Green City Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
982.0	1.5	0.6	
984.0	4.2	6.5	
986.0	8.3	18.8	
988.0	13.2	40.3	
990.0	19.9	73.2	
992.0	27.2	120.5	
994.0	32.0	179.6	
995.0	35.3	213.2	Lake Conditions on July 6, 2000
996.0	38.7	250.1	
998.0	46.3	334.8	
1,000.0	57.7	437.9	Principal Spillway
1,002.0	66.2	561.9	
1004.0	76.0	704.1	Emergency Spillway

[LIMITS]

Maximum storage……………………………………………………...438 acre-feet.
Minimum storage……………………………………………….6.52 and 50 acre-feet.
Drainage Basin Size (effective area)……………………..……….1.25 square miles.

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1952 through December 1959.

[SEEPAGE]

Seepage from Green City Reservoir is estimated to be approximately 1.00 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation values for the drought of record were obtained from Milan, Missouri

Average precipitation in Milan was 37.2 inches between 1950 and 2000. The most severe drought occurred between 1952 and 1957 with annual precipitation values in Milan of 28.01 inches, 26.22 inches, 34.07 inches, 36.22 inches, and 29.03 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Locust Creek gauge at Linneus. The drainage area monitored by this stream gauge covers approximately 550 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Milan, individual storm events were considered. Antecedent rainfall was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate direct runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Green City Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

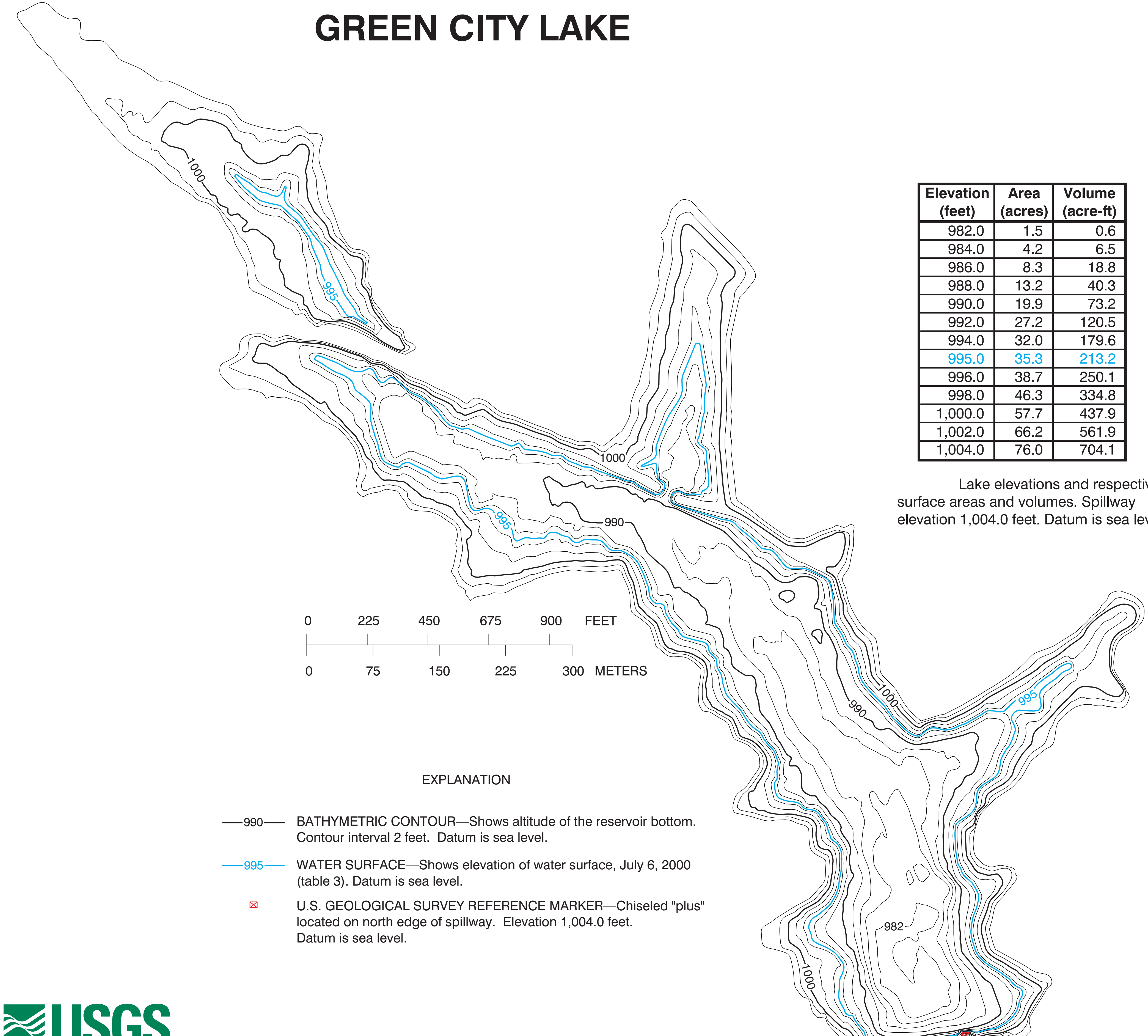
Green City has a daily use of 182,500 gallons per day.

City records reported to Missouri Department of Natural Resources 'Major water users data base' were used to determined demand (figure 15.2). In 1999 Green City used a total 66,653,344 gallons or 182,500 gallons of water per day.

GREEN CITY LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
982.0	1.5	0.6
984.0	4.2	6.5
986.0	8.3	18.8
988.0	13.2	40.3
990.0	19.9	73.2
992.0	27.2	120.5
994.0	32.0	179.6
995.0	35.3	213.2
996.0	38.7	250.1
998.0	46.3	334.8
1,000.0	57.7	437.9
1,002.0	66.2	561.9
1,004.0	76.0	704.1

Lake elevations and respective surface areas and volumes. Spillway elevation 1,004.0 feet. Datum is sea level.



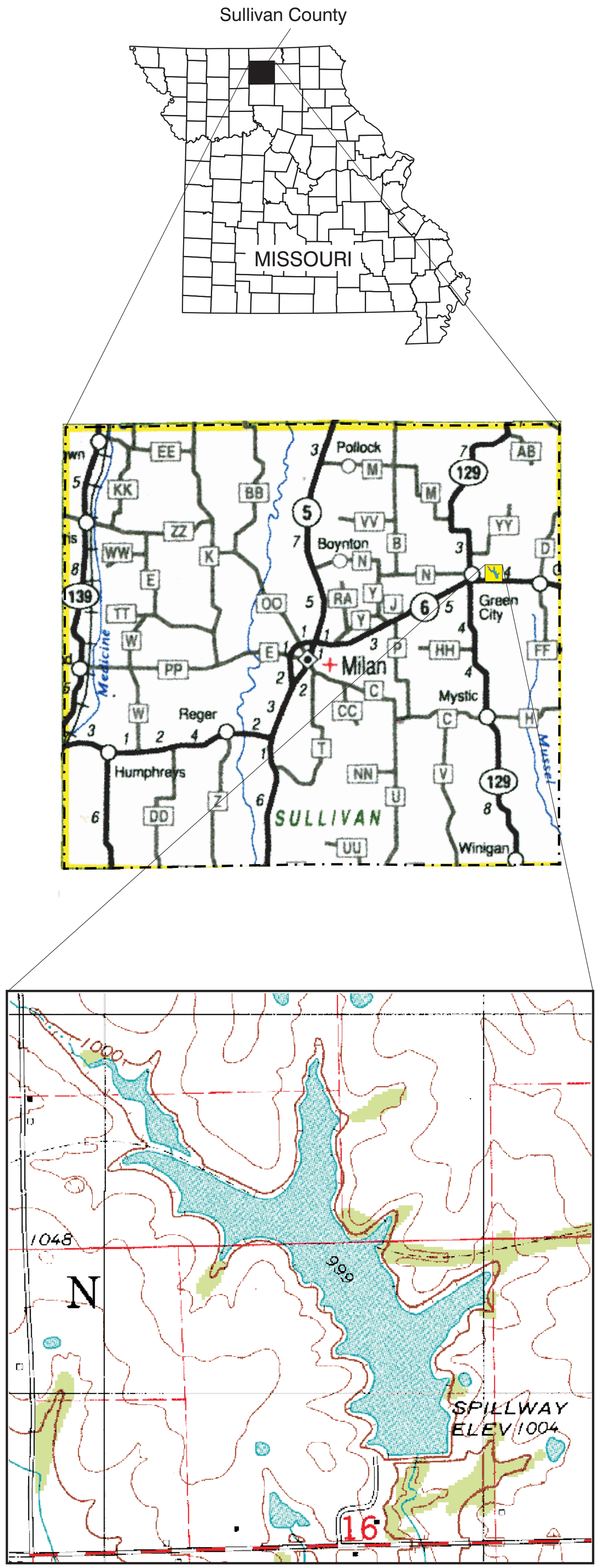
EXPLANATION

990 BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

995 WATER SURFACE—Shows elevation of water surface, July 6, 2000 (table 3). Datum is sea level.

U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled "plus" located on north edge of spillway. Elevation 1,004.0 feet. Datum is sea level.

LOCATION MAP



USGS
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Bathymetric map and area/volume table for Green City Lake near Green City, Missouri.

Figure 15.1

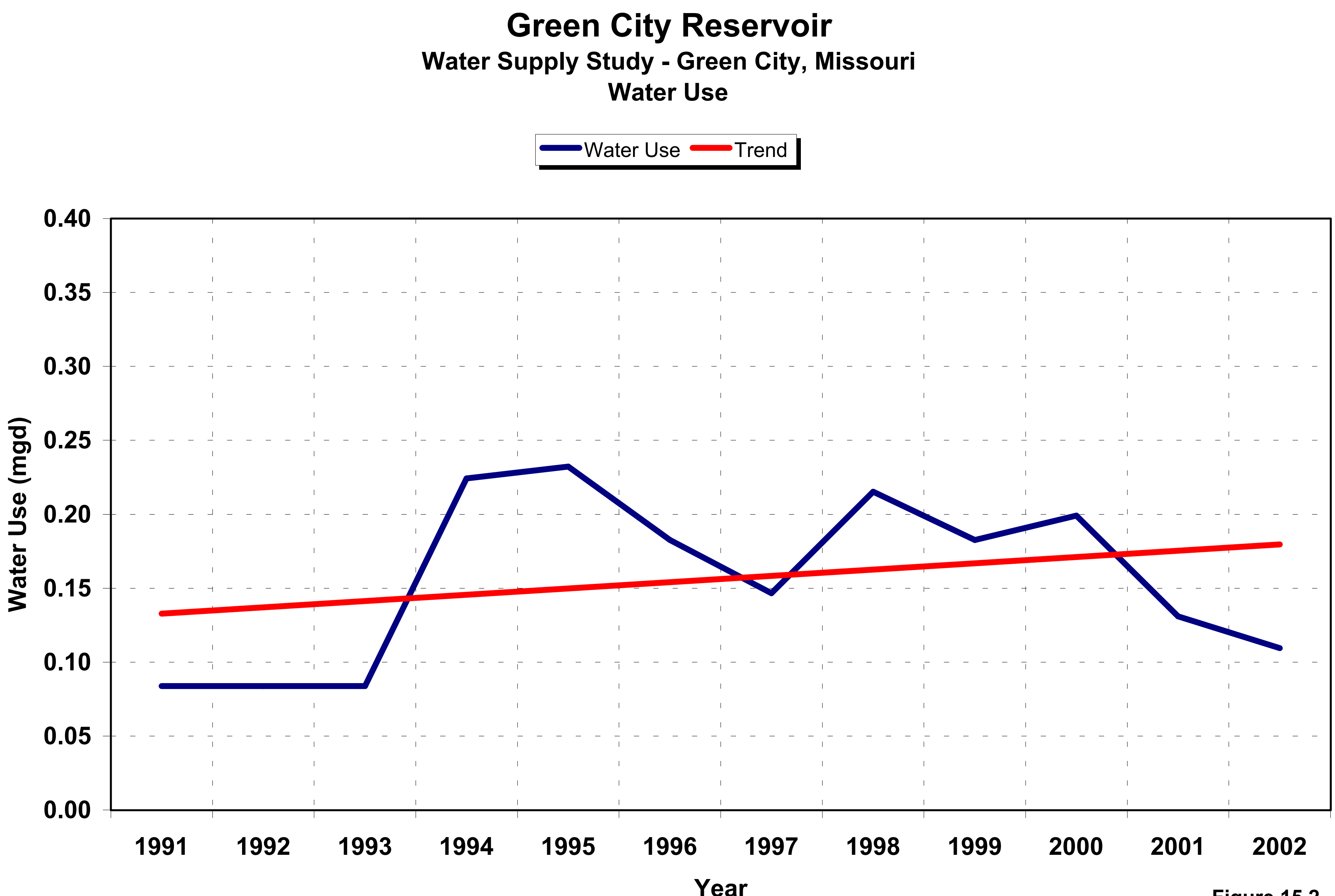

Green City Reservoir
Water Supply Study - Green City, Missouri
Water Use
Water Use
Trend
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Water Use (mgd)
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Year

Figure 15.2

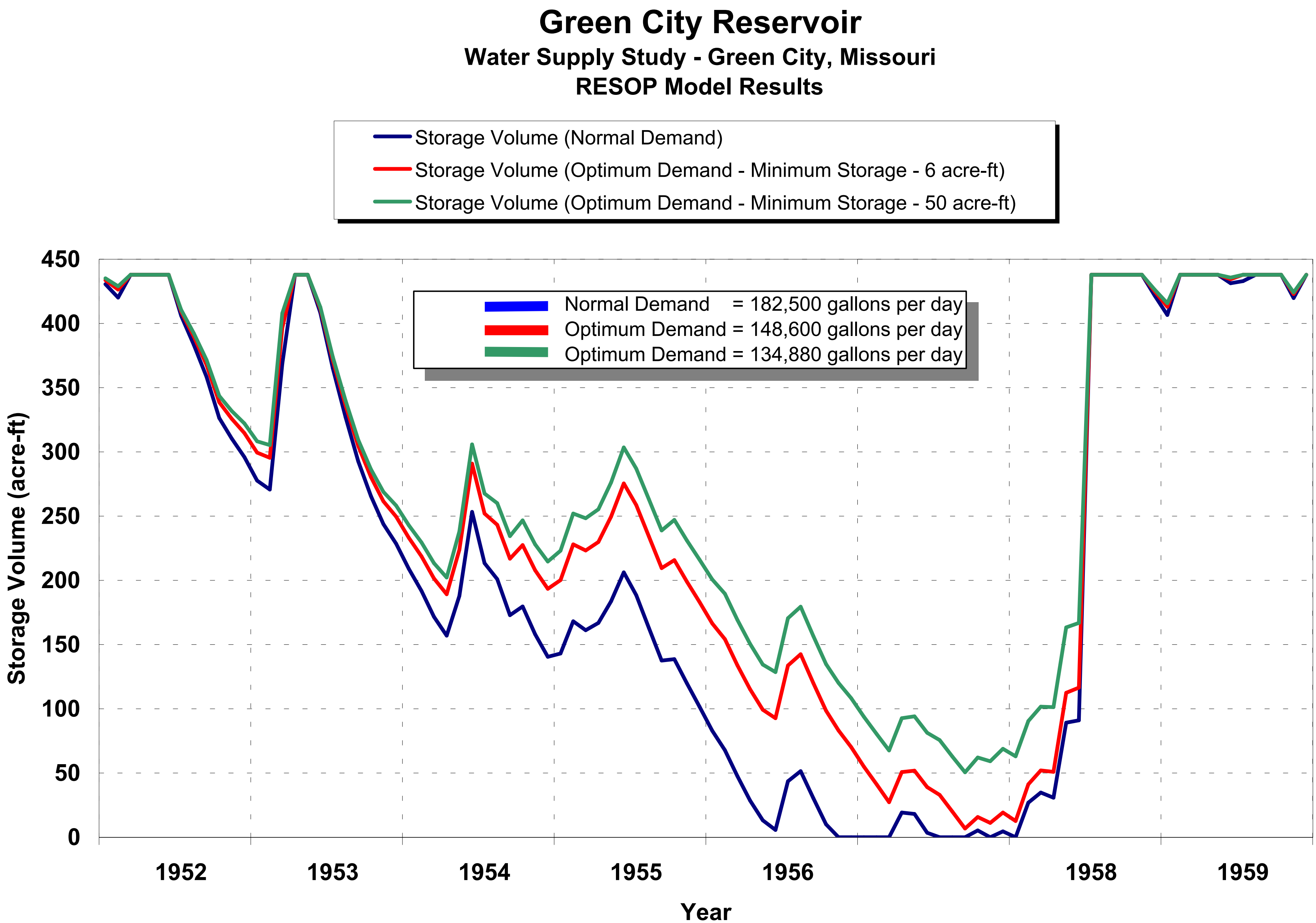

Green City Reservoir
Water Supply Study - Green City, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand - Minimum Storage - 6 acre-ft)
Storage Volume (Optimum Demand - Minimum Storage - 50 acre-ft)
Normal Demand = 182,500 gallons per day
Optimum Demand = 148,600 gallons per day
Optimum Demand = 134,880 gallons per day
Storage Volume (acre-ft)
450
400
350
300
250
200
150
100
50
0
1952
1953
1954
1955
1956
1958
1959
Year

Figure 15.3.a

Green City Reservoir
Water Supply Study - Green City, Missouri
RESOP Model Results

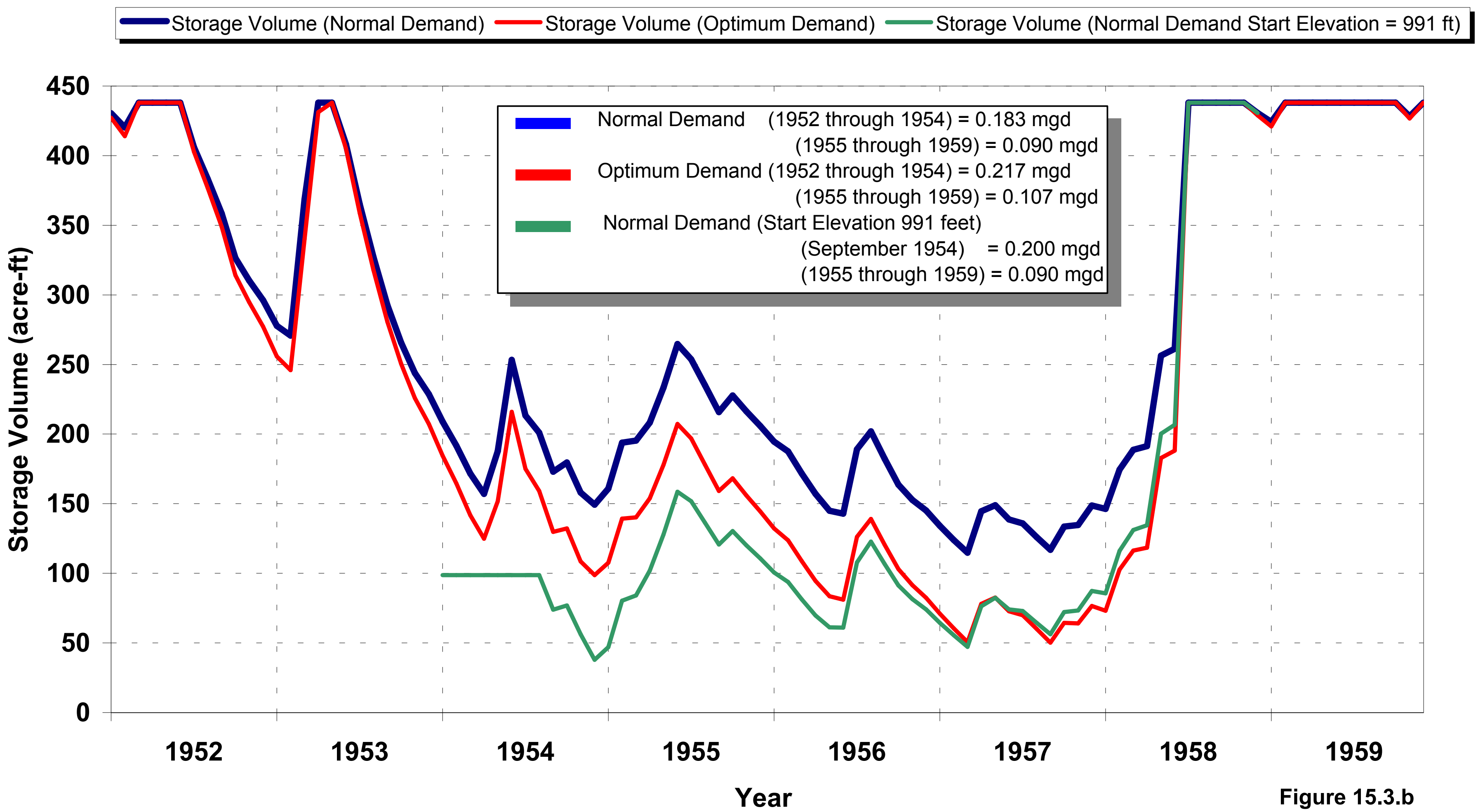


Figure 15.3.b

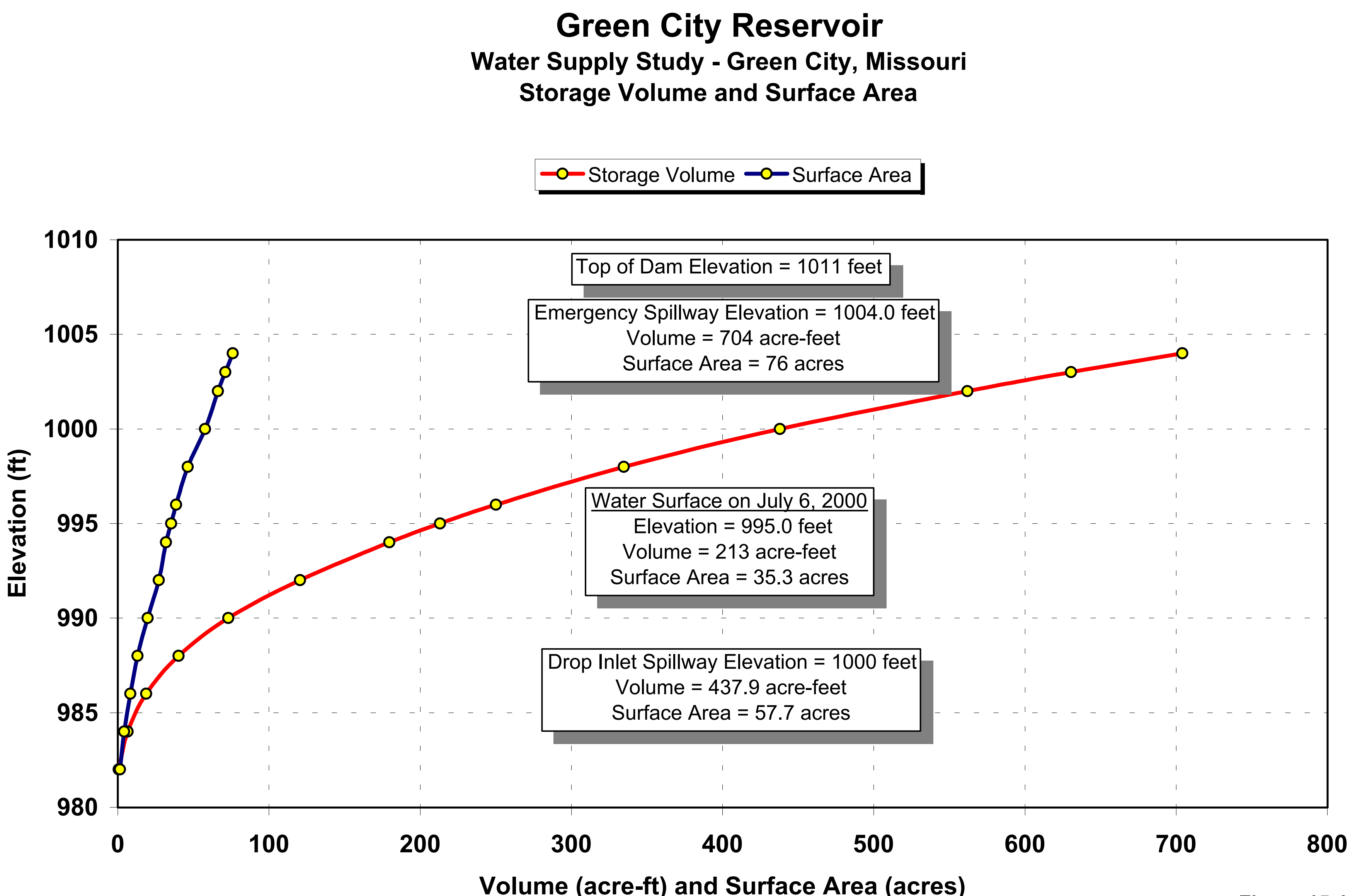

Green City Reservoir
Water Supply Study - Green City, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Top of Dam Elevation = 1011 feet
Emergency Spillway Elevation = 1004.0 feet
Volume = 704 acre-feet
Surface Area = 76 acres
Water Surface on July 6, 2000
Elevation = 995.0 feet
Volume = 213 acre-feet
Surface Area = 35.3 acres
Drop Inlet Spillway Elevation = 1000 feet
Volume = 437.9 acre-feet
Surface Area = 57.7 acres
Elevation (ft)
1010
1005
1000
995
990
985
980
0
100
200
300
400
500
600
700
800
Volume (acre-ft) and Surface Area (acres)

Figure 15.4

Hamilton Reservoir
Water Supply Study – Hamilton, Missouri
Drought Assessment Analysis

I. Overview

The Hamilton reservoir system (figure 16.1) is located two miles west of the City of Hamilton in north central Caldwell County, Missouri. The reservoir system is the primary source of drinking water for the City of Hamilton as well as Caldwell County PWSD (Public Water Supply District) # 2, which purchases all of its drinking water from Hamilton. The combined population served by the Hamilton reservoir system is approximately 1750 with an average consumption of 0.25 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

The lake is not large enough, both in drainage area and capacity, to meet all of the demand during extended periods of dry weather. The drainage area of the lake is 1142 acres (1.78 Sq. Mi.). The city has installed a pump to divert water from Marrowbone Creek to the lake. The drainage area at the point of intake is 38.2 square miles. The pump is rated at 1000 gallon per minute and pumping availability was analyzed and added to the inflow to the lake. Only when flow in the creek would meet needs for in-stream flow.

Hamilton reported using 180,000 gallon of water per day in year 2000 (figure 16.2). In addition, public water supply district #1 proposed to use another 80,000 gallons per day from Hamilton. The total demand would be 260,000 gallons per day. Water is now available in Little Otter Reservoir that is planned to be used to provide for Caldwell County demand for water.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

The lake would supply 180,000 gallons per day but get dangerously low at the beginning of 1958 with only 100-acre feet left in the lake (figure 16.3.a). Using the yearly demand of 260,000 gallons per day, the lake would be emptied all of 1957 into 1958 (figure 16.3.b). Optimized demand for this lake without diverting from Marrowbone Creek is 190,000 gallon per day.

II. Drought Assessment Summary

The Hamilton Reservoir is at risk of not meeting the community’s demand for water during times of drought without additional sources of water. The 2000 demand on the reservoir was approximately 180,000 gallons per day, and when this demand value is applied to the reservoir during the drought of record in the 1950’s, water for the 1,750 population could be met only if there were no increase in demand. The 1996 demand of 243,000 gallons per day would have resulted in water deficits in 1957 and 1958. The estimated optimum yield from Hamilton Reservoir is 190,000 gallons per day without additional water sources.

Caldwell County PWSD (Public Water Supply District) # 1 made a request to be added to Hamilton’s water supply, requesting 80,000 gallons per day. The addition of 80,000 gallons per day on the system would result in deficits in all of 1957 and through June 1958. By diverting water from Marrowbone Creek, when stream flow allows, the demand of 260,000 gallons per day can be met with 300 acre-feet remaining in the reservoir.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Hamilton Reservoir conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on July 11, 2000. These relationships are illustrated in figure 16.4.

Hamilton Lake Physical Data

Hamilton Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
901.0	0.42	0.14	
903.0	4.37	4.47	
905.0	10.98	19.35	
907.0	17.18	46.95	
909.0	23.41	86.83	
911.0	29.35	139.49	
913.0	39.17	207.91	
915.0	48.36	295.03	
917.0	61.39	404.06	
919.0	73.65	539.65	
921.0	82.09	695.49	
921.6	84.77	745.49	Lake Conditions July 11, 2000
923.0	90.50	868.80	
923.3	91.48	896.09	Spillway

[LIMITS]

Hamilton Lake
Maximum storage ....896 acre-feet
Minimum storage ....48 acre-feet
Drainage basin size .... 1.78 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity for both lakes.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from the primary lake was estimated to be 1.0 inches per month when the reservoir is at or near full capacity and 0.0 inches per month as the water level approaches the lower limits of

the pool. The earthen dam on the Adrian Reservoir is composed primarily of clay-rich materials and seepage through the dam is minimal.

[RAINFALL]

Precipitation rates from Butler, Missouri (approximately 8 miles south of Adrian) were used for this analysis and supplemented with data from Appleton City, Missouri. Average annual precipitation in Butler from 1970 through 2000 was 42.05 inches. Annual precipitation in Butler from 1953 through 1957 was 28.8 inches, 35.7 inches, 28.4 inches, 21.3 inches, and 37.5 inches, respectively.

[RAINFALL]

Precipitation values for the drought of record were obtained from the Gallatin, Missouri gauge.

Average precipitation in Gallatin was 36.6 inches between 1951 and 2001. Precipitation values for the drought of record were obtained from Gallatin, Missouri (approximately 14 miles north of Hamilton). The most severe drought occurred between 1953 and 1957 with annual precipitation values in Gallatin of 20.07 inches, 33.55 inches, 28.27 inches, 27.88 inches, and 42.38 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Jenkins Branch stream gauge (a tributary of the Platte River), located approximately 30 miles southwest of Hamilton. The drainage area monitored by this stream gauge covers approximately 2.72 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Hamilton, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Hamilton Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

Values for water usage by Hamilton are illustrated in figure 16.2. Hamilton water demand has varied from a high of 272,000 gallons per day in 1990 to a low of 173,000 gallons per day. This analysis assumed a normal demand to be 180,000 gallons per day without selling water to Caldwell County PWSD #2. With the PWSD the demand is 260,000 gallons per day. Optimum demand (yield) from Hamilton Reservoir without an additional source of water (pumping from the Marrowbone Creek) is 190,000 gallons per day.

[OTHER]

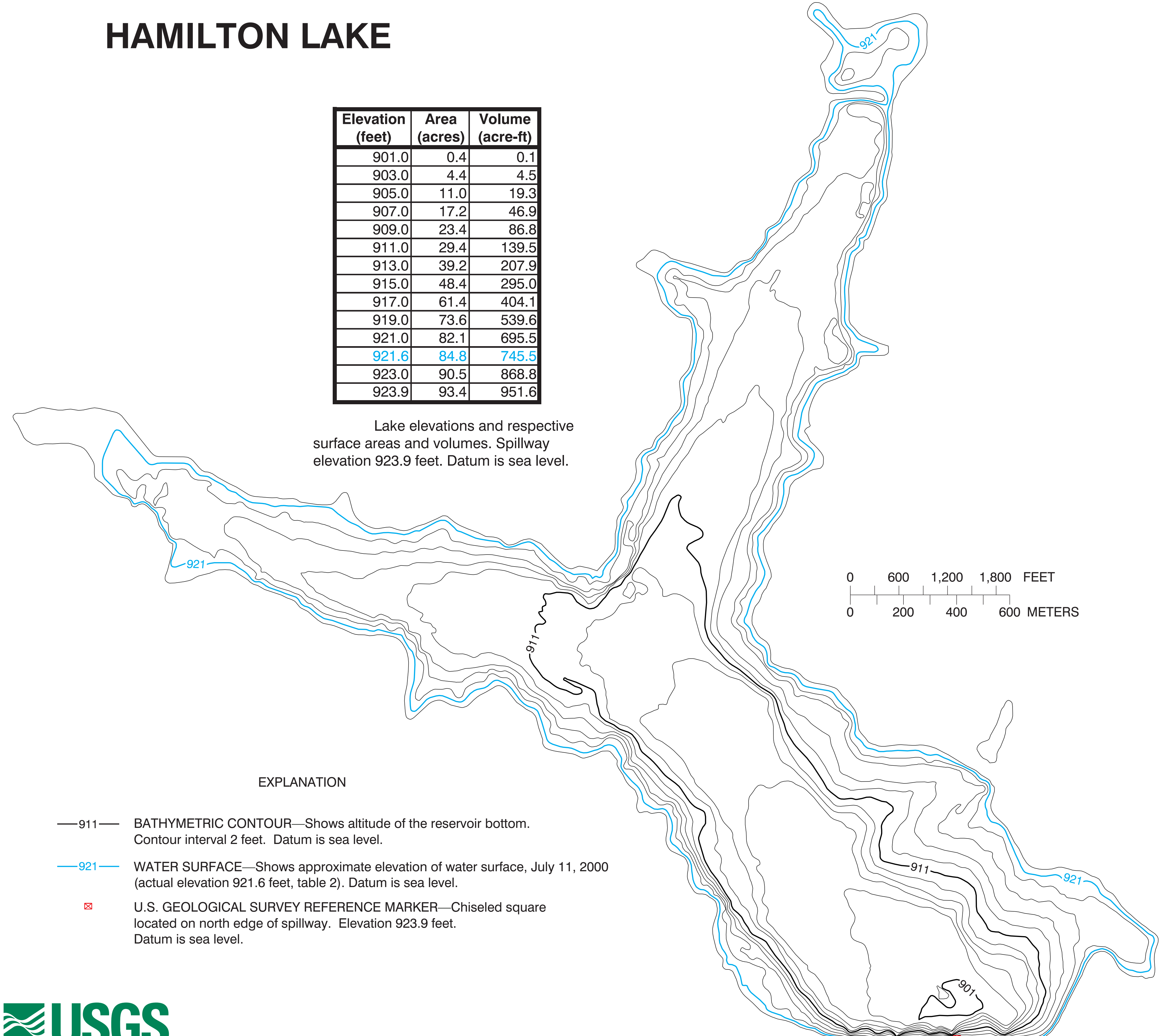
Additional water added to Hamilton's water supply is accomplished by diverting from Marrowbone Creek (drainage area of 38.2 square miles) by pumping into Hamilton's Reservoir. To determine if flow in the Marrowbone Creek has sufficient to allow pumping, the Crooked River gauge near Richmond Missouri (drainage area of 159 square miles) was evaluated. Adjustments to stream

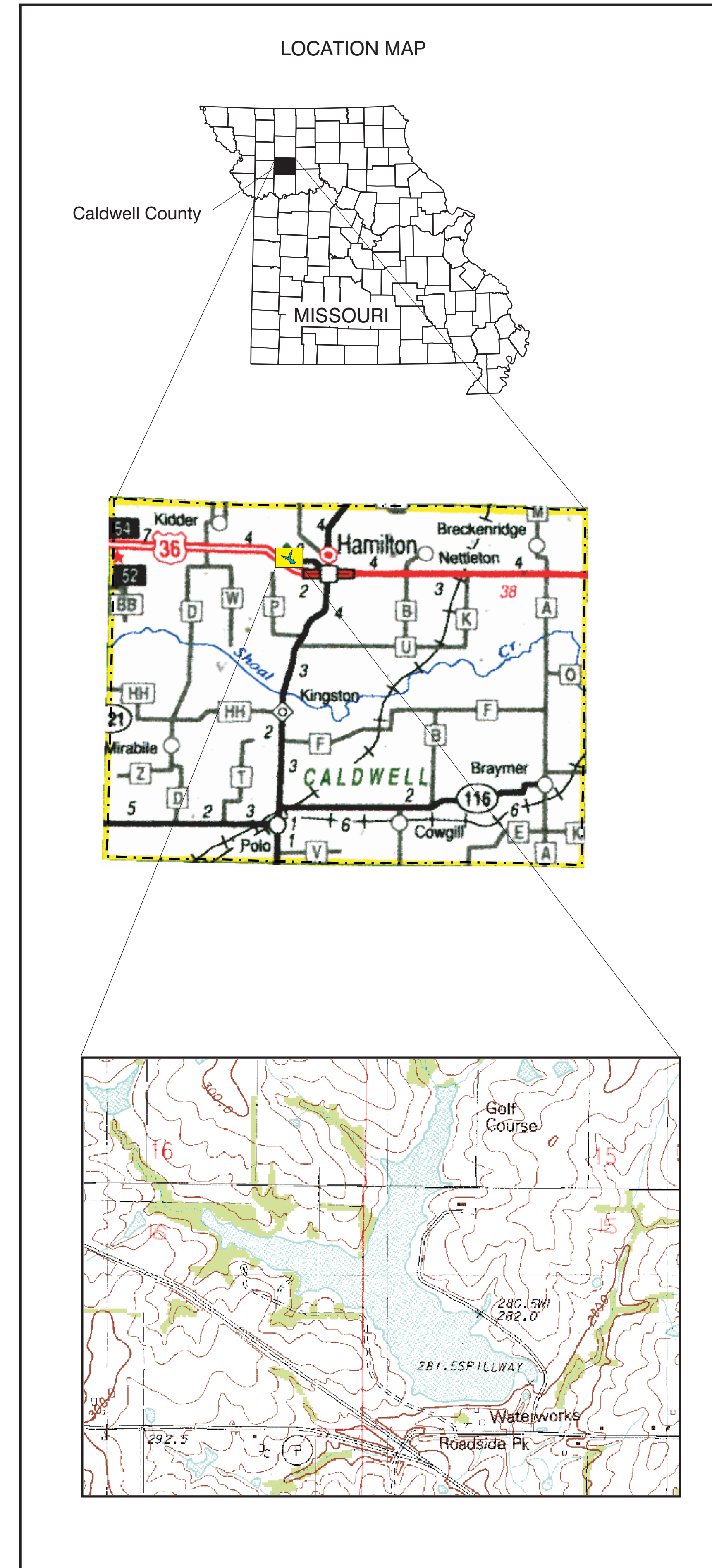
flow were made based on ratio of drainage areas. Only when low flows exceeded 7-day duration 10-year frequency low flow discharge (the amount determined for in-stream flow needs) was pumping allowed. The 7-day 10-year low flow was determined to be 2 cubic feet per second. Daily values were evaluated to establish the number of days available for pumping. The pump is rated at 1000 gallons per minute.

HAMILTON LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
901.0	0.4	0.1
903.0	4.4	4.5
905.0	11.0	19.3
907.0	17.2	46.9
909.0	23.4	86.8
911.0	29.4	139.5
913.0	39.2	207.9
915.0	48.4	295.0
917.0	61.4	404.1
919.0	73.6	539.6
921.0	82.1	695.5
921.6	84.8	745.5
923.0	90.5	868.8
923.9	93.4	951.6

Lake elevations and respective surface areas and volumes. Spillway elevation 923.9 feet. Datum is sea level.





EXPLANATION

—911— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—921— WATER SURFACE—Shows approximate elevation of water surface, July 11, 2000 (actual elevation 921.6 feet, table 2). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on north edge of spillway. Elevation 923.9 feet. Datum is sea level.

USGS
science for a changing world

Bathymetric map and area/volume table for Hamilton Lake near Hamilton, Missouri.

Figure 16.1

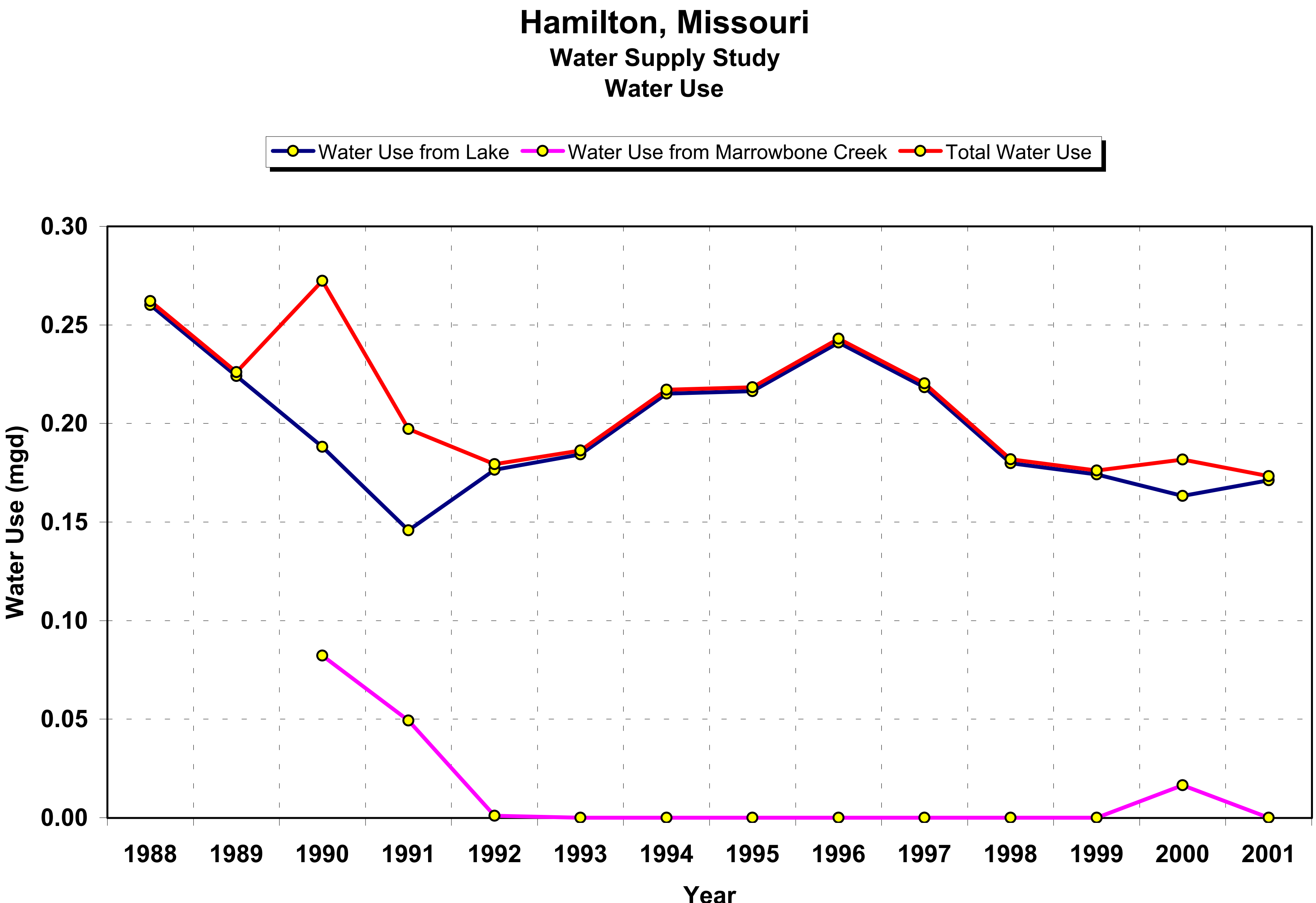

Hamilton, Missouri
Water Supply Study
Water Use
Water Use from Lake
Water Use from Marrowbone Creek
Total Water Use
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Water Use (mgd)
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 16.2

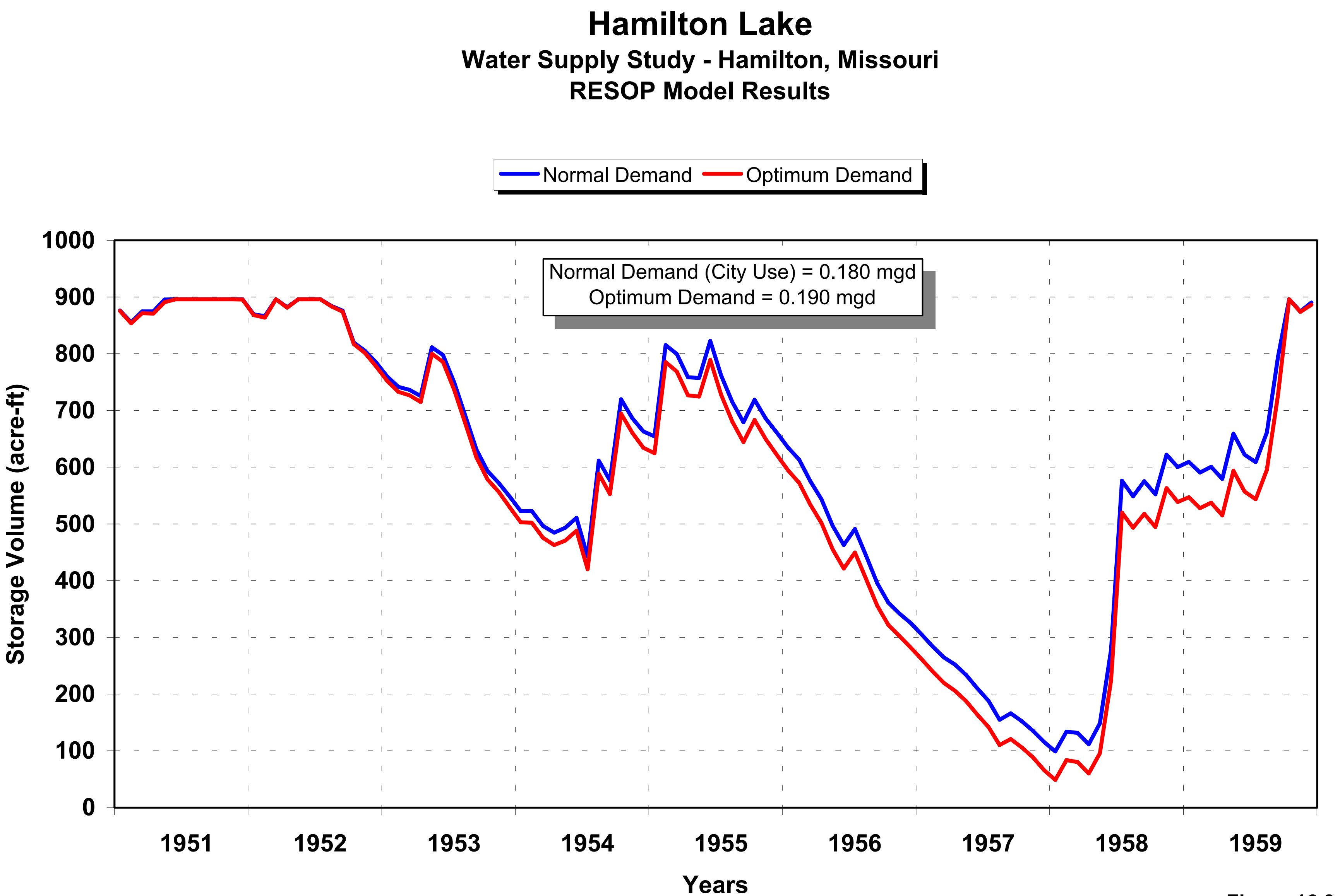

Hamilton Lake
Water Supply Study - Hamilton, Missouri
RESOP Model Results
Normal Demand
Optimum Demand
Normal Demand (City Use) = 0.180 mgd
Optimum Demand = 0.190 mgd
Storage Volume (acre-ft)
1000
900
800
700
600
500
400
300
200
100
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 16.3.a

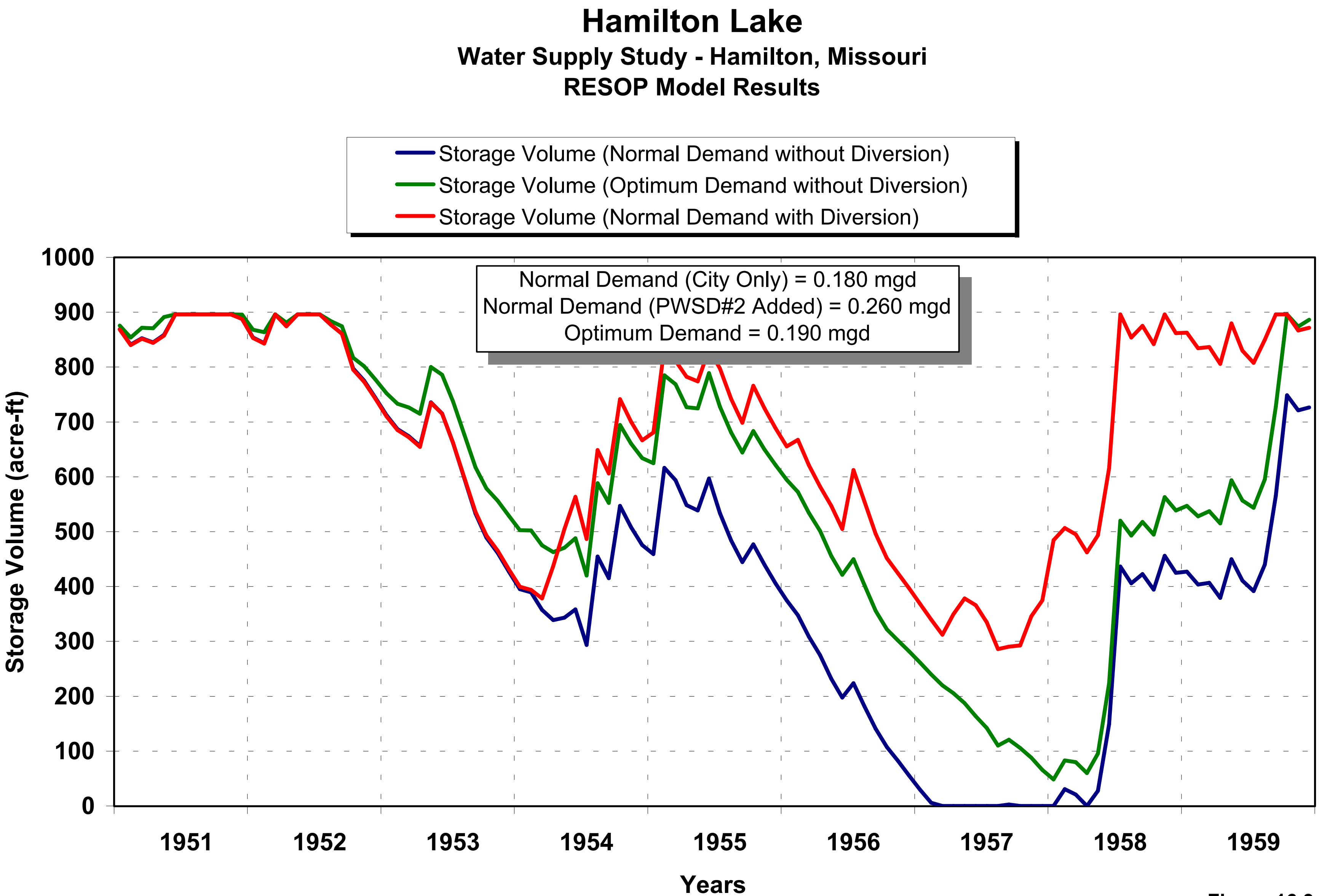

Hamilton Lake
Water Supply Study - Hamilton, Missouri
RESOP Model Results
Storage Volume (Normal Demand without Diversion)
Storage Volume (Optimum Demand without Diversion)
Storage Volume (Normal Demand with Diversion)
Normal Demand (City Only) = 0.180 mgd
Normal Demand (PWSD#2 Added) = 0.260 mgd
Optimum Demand = 0.190 mgd
Storage Volume (acre-ft)
1000
900
800
700
600
500
400
300
200
100
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 16.3.b

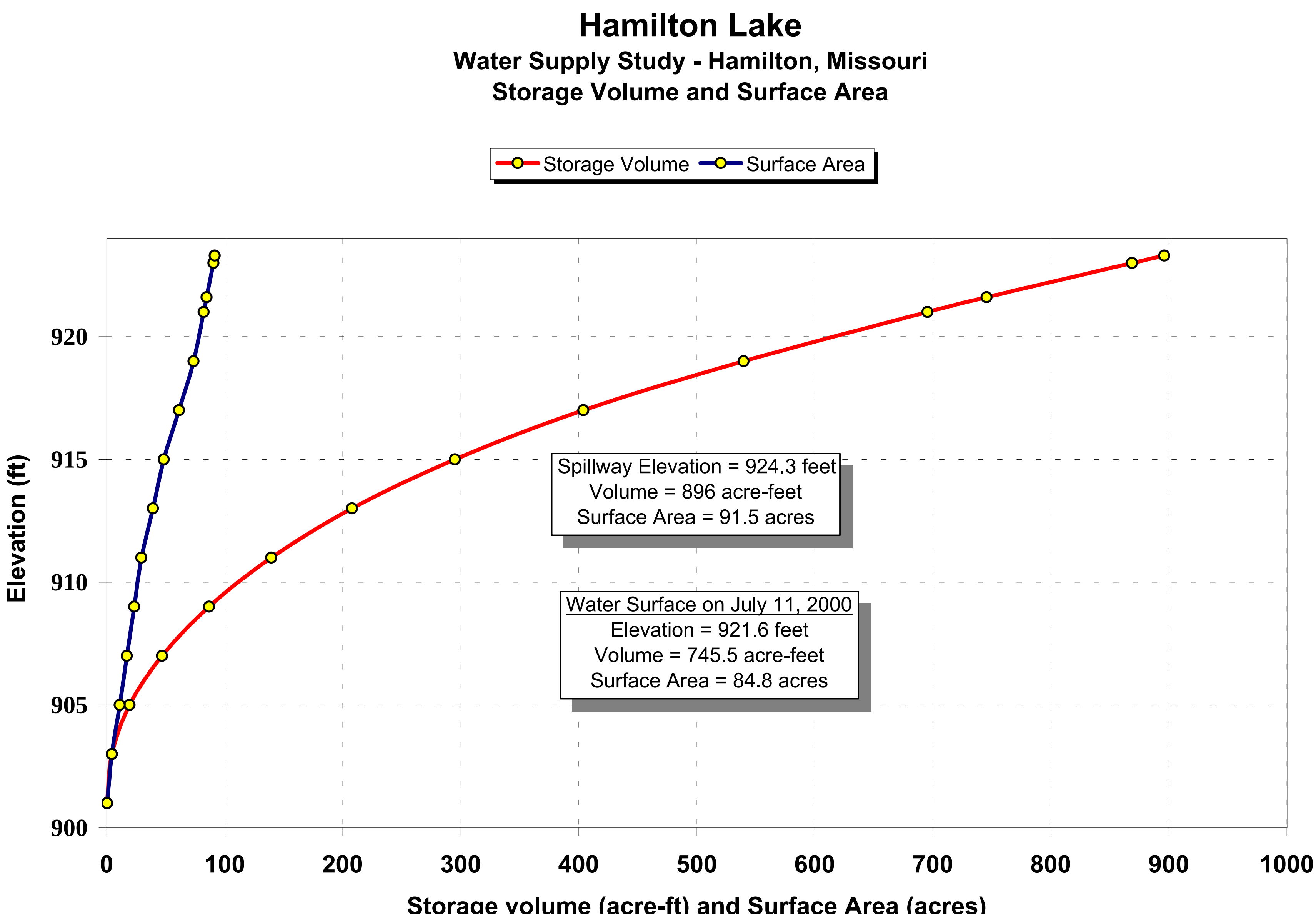

Hamilton Lake
Water Supply Study - Hamilton, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 924.3 feet
Volume = 896 acre-feet
Surface Area = 91.5 acres
Water Surface on July 11, 2000
Elevation = 921.6 feet
Volume = 745.5 acre-feet
Surface Area = 84.8 acres
Elevation (ft)
900
905
910
915
920
0
100
200
300
400
500
600
700
800
900
1000
Storage volume (acre-ft) and Surface Area (acres)

Figure 16.4

Eagleville Lake
Harrison County PWSD #1
Drought assessment analysis

In the 2002 Harrison County Public Water Supply District #1 changed to Harrison County Lake for their water supply source. In the past, Eagleville Lake (figure 17.1) supplied water for Harrison County PWSD #1. This lake was built as part of the USDA Soil Conservation Service East Fork Big Creek PL-566 in cooperation with East Fork Big Creek Conservancy District's watershed project. It does not have planned water supply as part of the design of the lake. Water is drawn from the sediment pool. At the time of construction Eagleville elected not to include municipal water supply but requested use of the water in the sediment pool. As a result the lake is shallow. Because the lake is shallow, evaporation can be high. A holding basin for additional storage has been constructed downstream of the lake. There is a 2,290 feet long, 12-inch diameter pipe connecting the lake and the basin. The overflow elevation for the basin is the same elevation as the spillway of the lake and is at elevation 991.3 feet. As a result the pipe connecting the two water bodies serves as an equalization medium so that the water level is the same for each reservoir. The Harrison County PWSD #1 serves a population of approximately 900 with an estimated water demand of 0.06 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

Harrison County Public Water Supply District #1 draws water directly from the reservoir to the treatment facility. Historical demand on the reservoir in 2000 was reported to be 86,000 gallons per day. Figure 17.2 illustrates historical water demand on the Eagleville Reservoir.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Two scenarios were modeled for Eagleville Reservoir. The model assumes that year 2000 'Normal' demand for Eagleville is 86,000 gallons per day and that 'Optimum' yield from the lake is 43,600 gallons per day. Figure 17.3.a illustrates these relationships. Figure 17.3.b model shows remaining storage in the reservoir plus the basin. The RESOP model shows the normal and optimum analyses are about the same with normal demand being 86,000 gallons per day and optimum demand to be 87,000 gallons per day.

The existing demand in year 2000 was 86,000 gallon per day. Optimized demand from the lake without the downstream storage basin is 43,600 gallon per day and the optimized demand from the lake in combination with the downstream storage basin is 87,000 gallon per day.

II. Drought Assessment Summary

The Eagleville Reservoir is at risk of not meeting the community's demand for water, during times of drought without use of the storage basin. The 2004 demand on the reservoir was approximately 59,000 gallons per day, and when this demand value is applied to the reservoir during the drought of record in the 1950's, water deficits would have occurred in August 1957 and between October 1957 through January 1958, and in April 1958. The estimated firm yield from Eagleville Reservoir is 52,000 gallons per day without additional water sources.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Eagleville Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on May 28, 2003. Surface area of the lake and associated storage volume capacities are illustrated in figure 17.4.a and 17.4.b. To determine total storage jointly in the basin, storage was estimated based on a surface area of 1.56 acres and a depth of 16 feet. The combined values for the basin were determined by adding the lake and basin together. Following is the results of the lake survey.

Eagleville Lake physical data

Eagleville Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
985.0	3.4	1.0	
986.0	7.9	6.8	
987.0	11.4	16.4	
988.0	15.3	29.8	
989.0	20.7	47.4	Lake conditions May 28, 2003
990.0	25.7	70.7	
991.0	27.7	97.6	
991.3	28.2	111.6	Spillway

Because the overflows at spillway elevation are the same, the lake and downstream basin are at the same elevation, as a result they were treated as one basin. To treat the lake and basin as one reservoir the following table was used.

Eagleville Reservoir plus Storage Basin			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
973.0	0.0	0.0	
974.0	1.56	0.8	
976.0	1.56	3.9	
978.0	1.56	7.1	
980.0	1.56	10.2	
982.0	1.56	13.3	
984.0	1.56	16.5	
985.0	5.0	19.1	
986.0	9.5	26.4	
987.0	13.0	37.6	
988.0	16.7	52.6	
989.0	22.3	71.7	
990.0	27.3	96.6	
991.0	29.3	125.1	
991.3	29.8	139.5	Spillway

[LIMITS]

Eagleville Reservoir
Maximum storage ....111.6 acre-feet
Minimum storage ....5.5 acre-feet
Drainage basin size .... 7.40 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

Eagleville Reservoir including Basin
Maximum storage ....139.5 acre-feet
Minimum storage ....5.5 acre-feet
Drainage basin size .... 7.40 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Eagleville Lake is estimated to be approximately 1.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials.

[RAINFALL]

Precipitation values for this analysis were obtained at Bethany, Missouri.

Average precipitation in Eagleville was 36.4 inches between 1950 and 2000. Precipitation values for the drought of record were obtained from Bethany, Missouri (approximately 14 mile south of Eagleville). The most severe drought occurred between 1953 and 1957 with annual precipitation values in Bethany of 24.09 inches, 32.05 inches, 27.00 inches, 24.31 inches, and 32.27 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the East Fork Big Creek stream gauge, located at Bethany, Missouri. The drainage area monitored by this stream gauge covers approximately 95 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Eagleville, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service’s (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

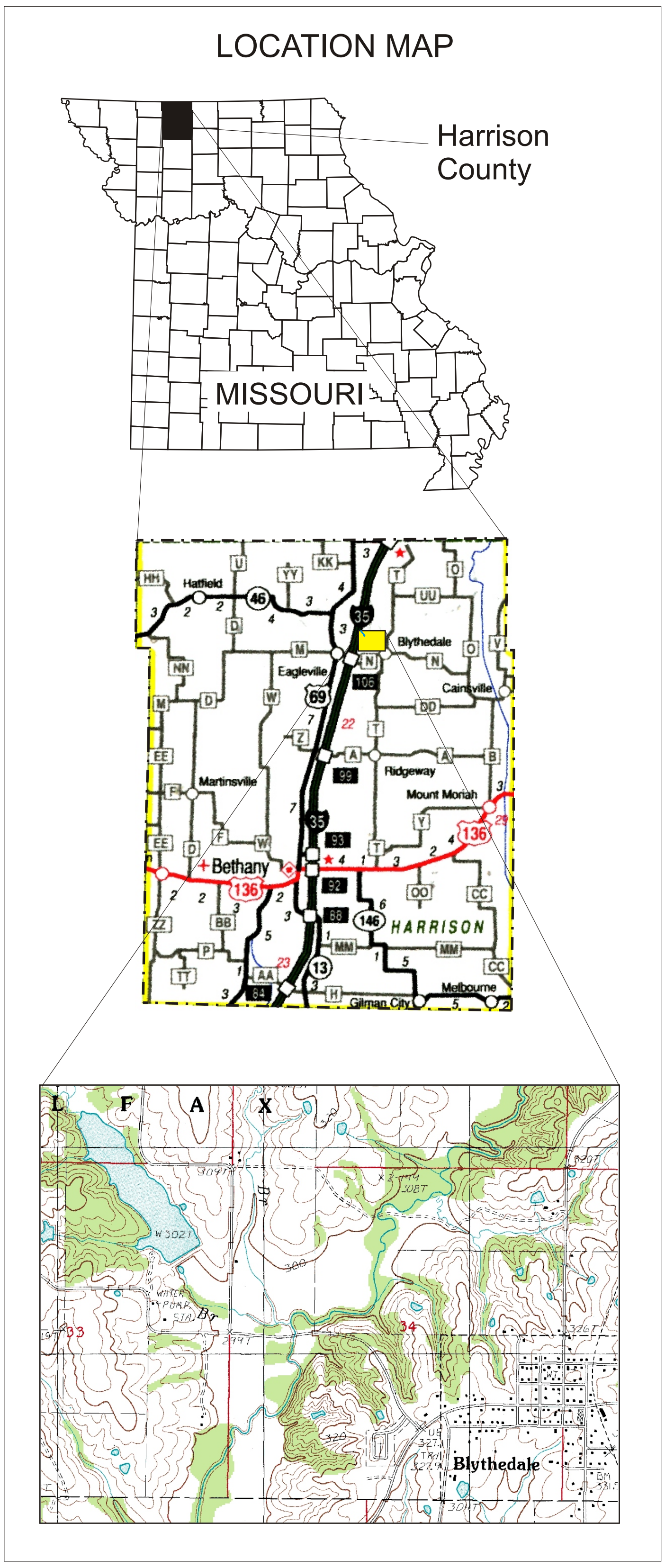
[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Rock House Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

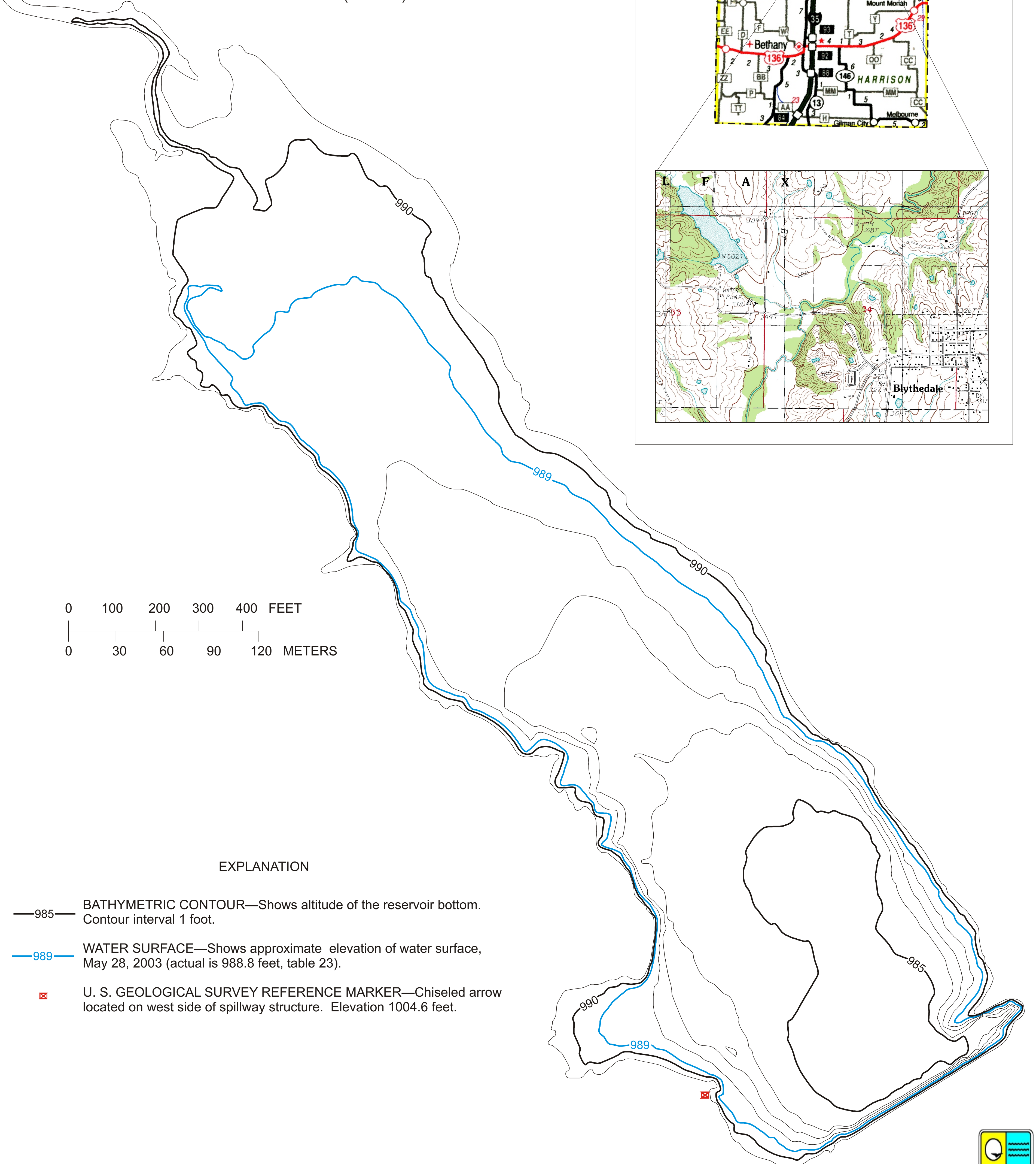
The water use for this study occurred in year 2000 averaging 86,000 gallons per day. Figure 17.2 illustrates water use reported to “Missouri Department of Natural Resources” major water users database determined water demand. Eagleville reported using 30,660,000 gallons of water in 2000 for an average 86,000 gallons of water per day.

EAGLEVILLE LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
985.0	3.4	1.0
986.0	7.9	6.8
987.0	11.4	16.4
988.0	15.3	29.8
989.0	20.7	47.4
990.0	25.7	70.7
991.0	27.7	97.6

Table 17.1 Lake elevations and respective surface areas and volumes. Top of spillway structure is 991.3 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).



0 100 200 300 400 FEET

0 30 60 90 120 METERS

EXPLANATION

—985— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 1 foot.

—989— WATER SURFACE—Shows approximate elevation of water surface, May 28, 2003 (actual is 988.8 feet, table 23).

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west side of spillway structure. Elevation 1004.6 feet.

Figure 17.1

USGS
science for a changing world

Figure 17.1 Bathymetric map and table of areas/volumes of Eagleville Lake near Blythedale, Missouri.

In cooperation with Missouri Department of Natural Resources

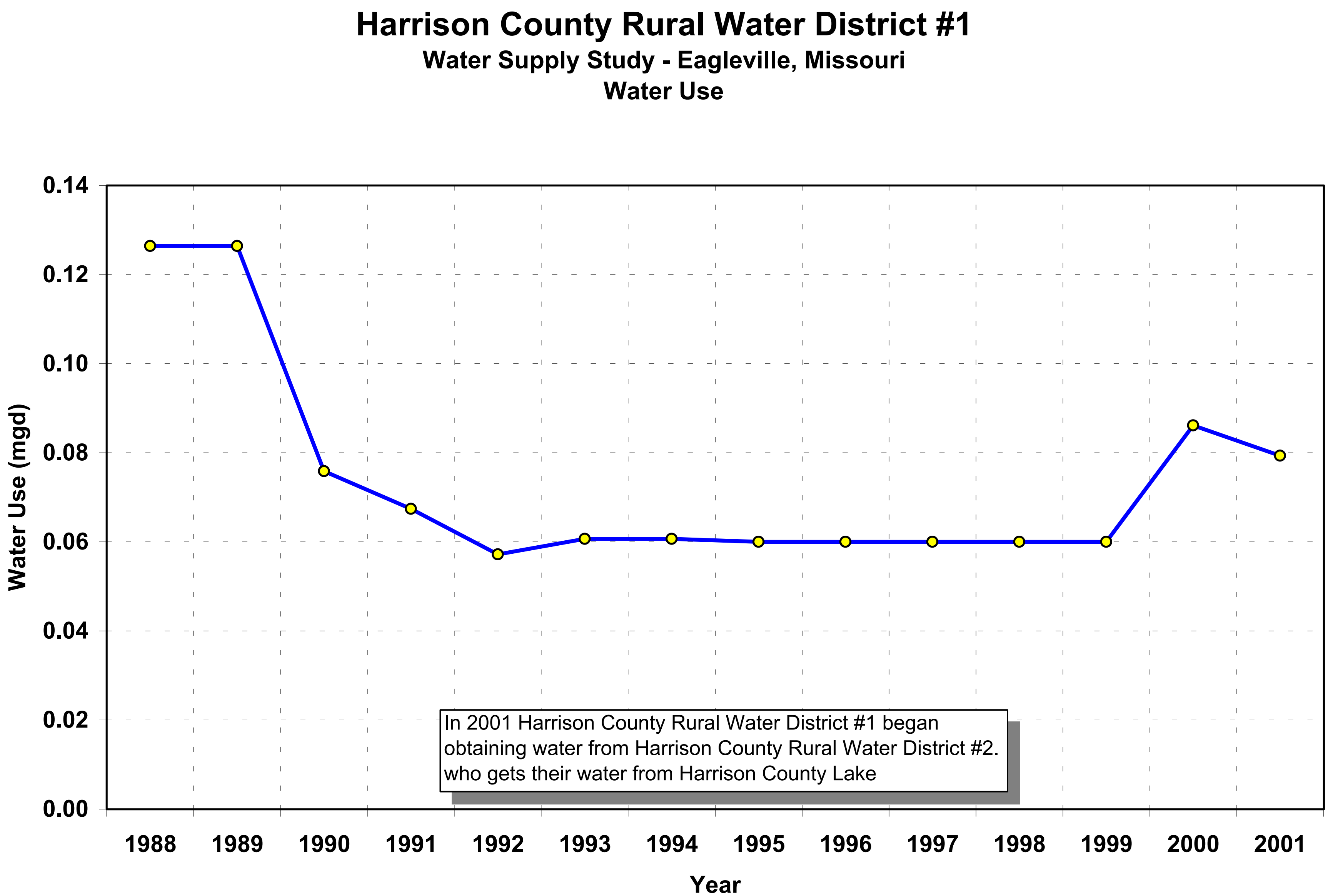

Harrison County Rural Water District #1
Water Supply Study - Eagleville, Missouri
Water Use
Water Use (mgd)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
In 2001 Harrison County Rural Water District #1 began obtaining water from Harrison County Rural Water District #2. who gets their water from Harrison County Lake

Figure 17.2

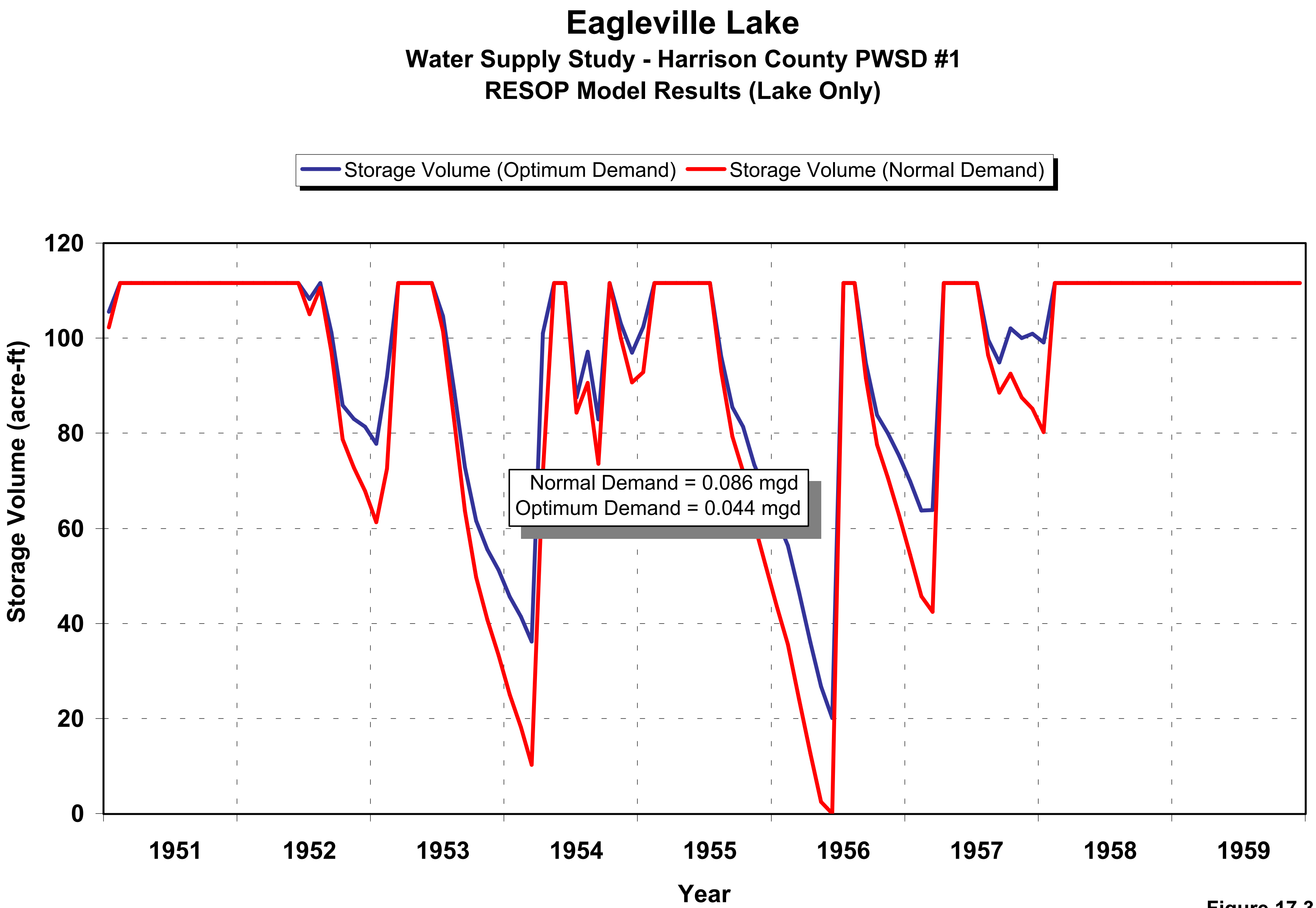

Eagleville Lake
Water Supply Study - Harrison County PWSD #1
RESOP Model Results (Lake Only)
Storage Volume (Optimum Demand)
Storage Volume (Normal Demand)
Normal Demand = 0.086 mgd
Optimum Demand = 0.044 mgd
120
100
80
60
40
20
0
Storage Volume (acre-ft)
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 17.3.a

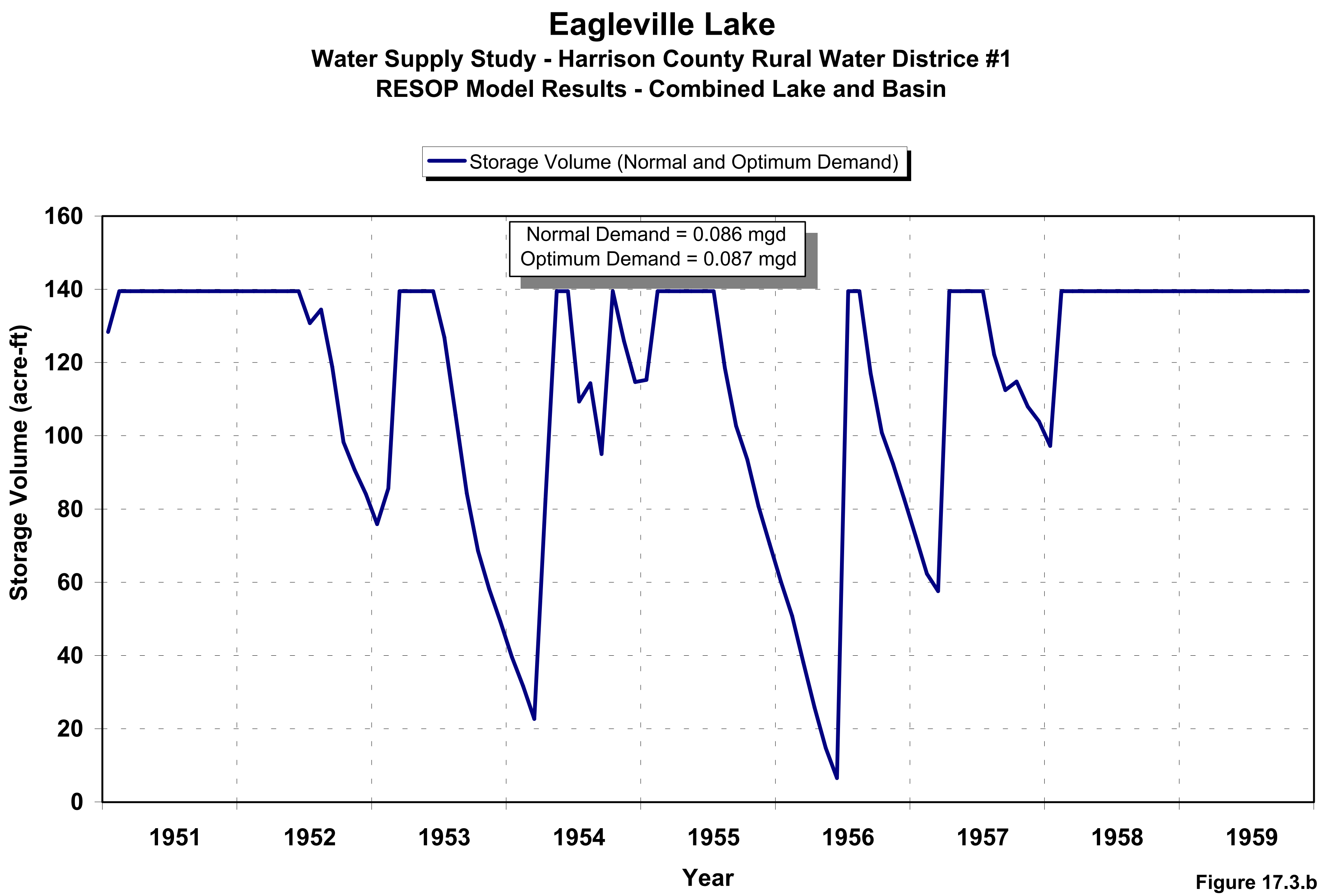

Eagleville Lake
Water Supply Study - Harrison County Rural Water Districe #1
RESOP Model Results - Combined Lake and Basin
Storage Volume (Normal and Optimum Demand)
Normal Demand = 0.086 mgd
Optimum Demand = 0.087 mgd
160
140
120
100
80
60
40
20
0
Storage Volume (acre-ft)
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 17.3.b

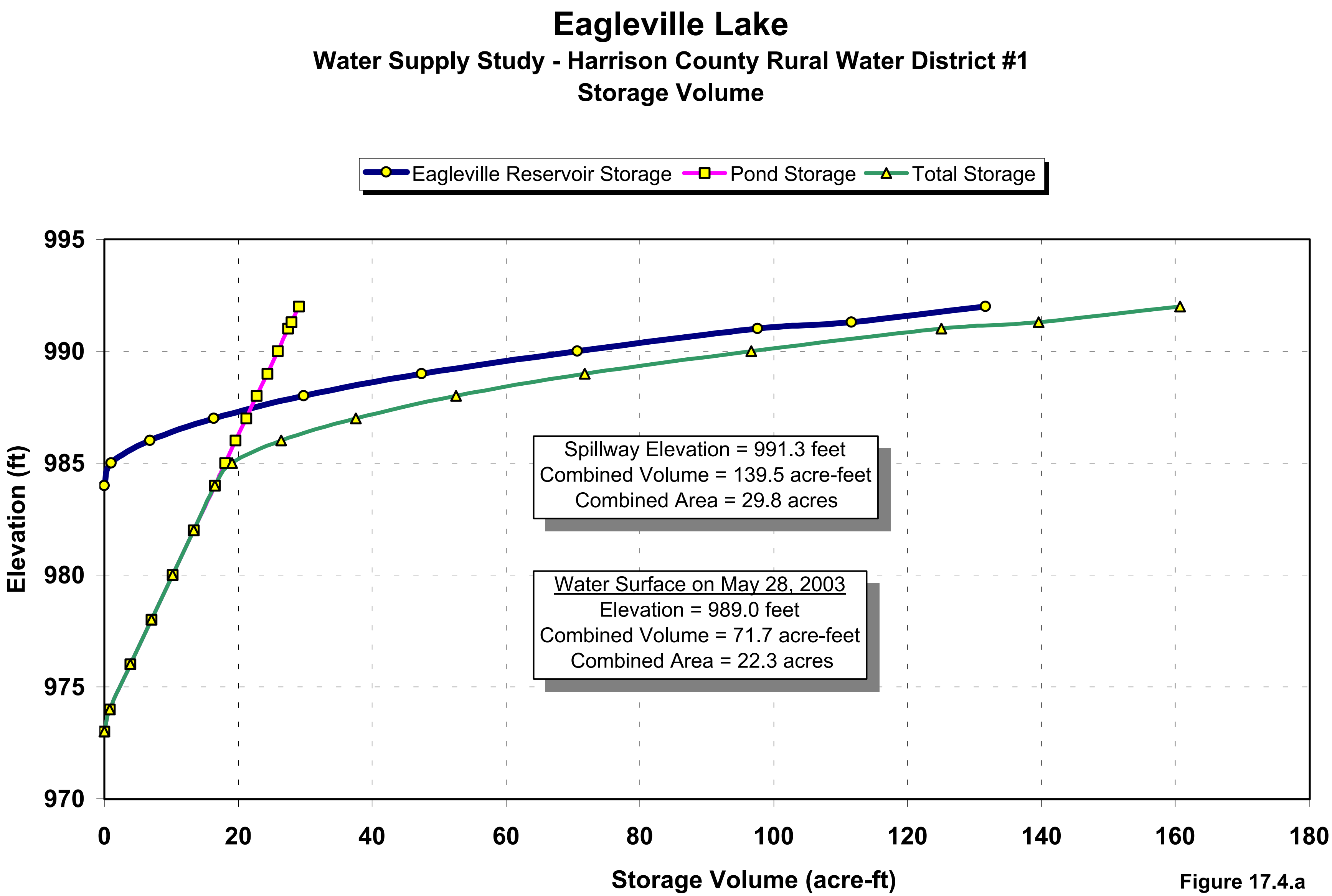

Eagleville Lake
Water Supply Study - Harrison County Rural Water District #1
Storage Volume
Eagleville Reservoir Storage
Pond Storage
Total Storage
995
990
985
980
975
970
Elevation (ft)
0
20
40
60
80
100
120
140
160
180
Storage Volume (acre-ft)
Spillway Elevation = 991.3 feet
Combined Volume = 139.5 acre-feet
Combined Area = 29.8 acres
Water Surface on May 28, 2003
Elevation = 989.0 feet
Combined Volume = 71.7 acre-feet
Combined Area = 22.3 acres

Figure 17.4.a

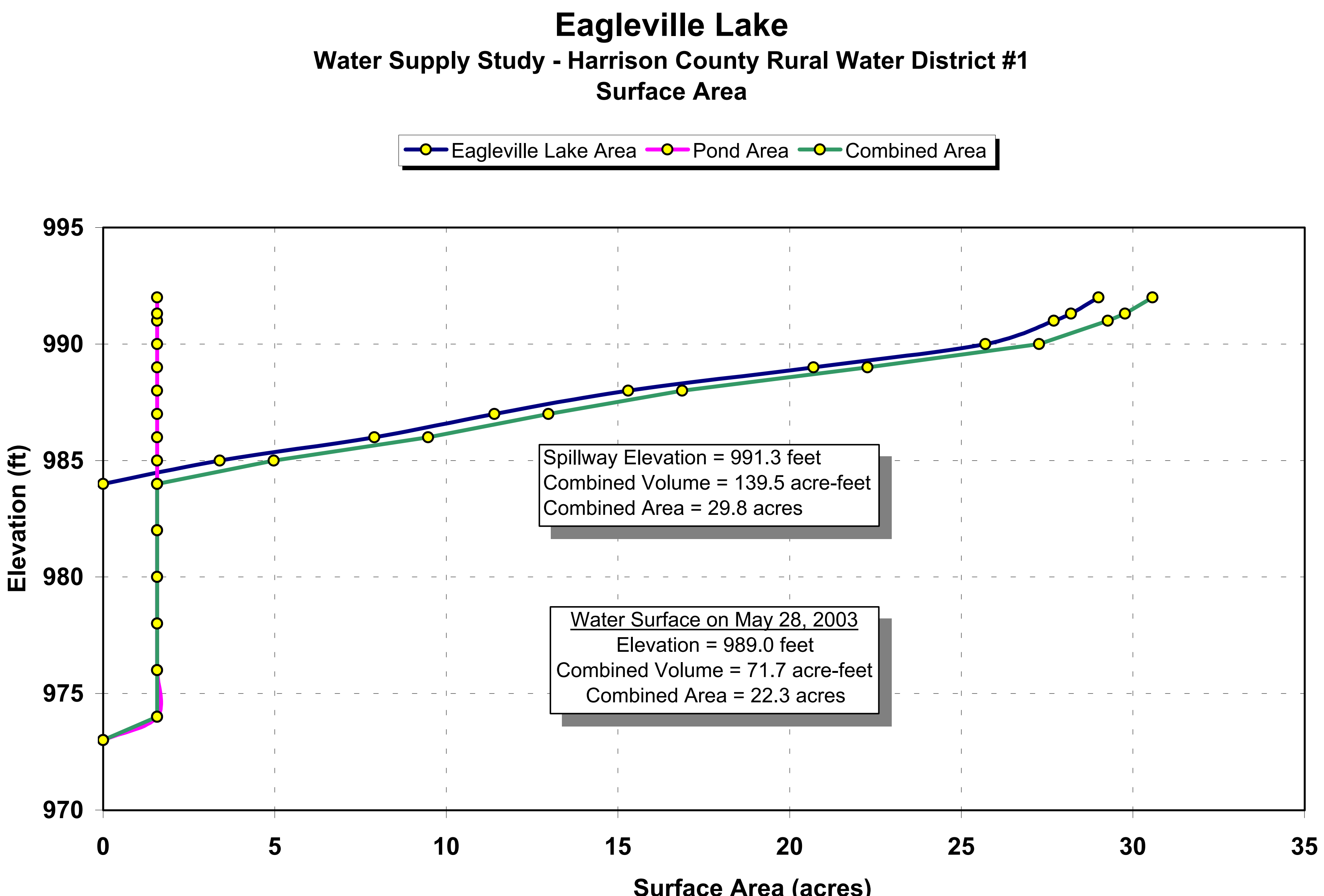

Eagleville Lake
Water Supply Study - Harrison County Rural Water District #1
Surface Area
Eagleville Lake Area
Pond Area
Combined Area
995
990
985
980
975
970
Elevation (ft)
0
5
10
15
20
25
30
35
Surface Area (acres)
Spillway Elevation = 991.3 feet
Combined Volume = 139.5 acre-feet
Combined Area = 29.8 acres
Water Surface on May 28, 2003
Elevation = 989.0 feet
Combined Volume = 71.7 acre-feet
Combined Area = 22.3 acres

Figure 17.4.b

Harrisonville Reservoir
Drought Assessment analysis
Harrisonville, Missouri

I. Overview

Harrisonville City Reservoir (figure 18.1) is located seven miles North of Harrisonville, Cass County, on a tributary to Big Creek. The reservoir provides water to Harrisonville and Cass County PWSD #10. They also have a well that can supply up to 509,000 gallons of water per day. The Harrisonville Reservoir serves a population of approximately 8,186 with a demand of 1.25 million gallons per day according to the 2008 census of Missouri Public Water systems (maintained by the Public Drinking Branch, Department of natural Resources).

The City of Harrisonville draws water directly from the reservoir to the treatment facility. Historical demand on the reservoir in 2003 was reported to be 1.32 million gallons per day. The demand 2008 is reported to be 1.25 million gallons per day. The demand for this analysis was 1.40 million gallons per day. Figure 18.2 illustrates historical water use on the Harrisonville Reservoir.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Harrisonville Reservoir. Although one groundwater well is available to supplement this water supply, the contribution of this well to available supplies was not considered within the context of this model. The model assumes that ‘Normal’ demand for Harrisonville to be 1.40 million gallons per day and that ‘Optimum’ yield from the reservoir is 1.54 million gallons per day. Figure 18.3 illustrates these relationships.

II. Drought Assessment Summary

This analysis shows that the Harrisonville Reservoir would supply an average daily demand of 1.40 million gallons per day. Optimum demand is determined to be 1.54 million gallons per day. Demand has been as high as 1.64 million gallons per day in 1989 and a low of 1.04 million gallons per day in 1994. From 1994 to 2004 demand has increasing at the rate of 25,000 gallons per day. As the city grows they will need to increase their water storage capacity. Current demand would have lowered the lake volume to about 1500-acre feet of storage 1957. The ground water well is capable of supplying 509,000 gallons of water per day.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Harrisonville Reservoir Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri

Department of Natural Resources on March 21, 2008. Surface area of the lake and associated storage volume capacity are illustrated in figure 18.4

Harrisonville Reservoir Physical Data

Harrisonville Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	
660.0	0.50	0.30	
664.0	10.1	16.0	
668.0	39.1	110	
682.0	105	381	
676.0	177	954	
680.0	229	1,770	
684.0	280	2,780	
688.0	325	4,000	
692.0	377	5,390	
696.0	427	6,990	Spillway and lake conditions on March 21, 2008

[LIMITS]

Maximum storage……………………………………………………………………6990 acre-feet
Minimum storage………………………………………………………………….1000 acre-feet
Drainage Basin size………………………………………………………..14.88 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought is in the 1950's. The analysis used in this model is January 1951 and ended December 1959.

[SEEPAGE]

Seepage from Harrisonville Reservoir is estimated to be 4.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation values for the drought of record were obtained from the Harrisonville, Missouri rain gauge.

Average annual precipitation for the 1951 through 2000 is 36.7. The most severe drought occurred between 1953 through 1957 with annual precipitation values of 28.8, 35.7, 28.4, 21.33, and 37.55 inches, respectively. Most of the 1957 rainfall occurred in the last three months of the year. As a result the most critical period of water storage is in the summer of 1957.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from Backwater River gauge near Blue Lick for the period 1951 through 1954 and South Fork Blackwater River gauge near Elm for the period 1954 through 1959. When this regional runoff value is inconsistent with precipitation values for Harrisonville, daily precipitation rates were considered. Antecedent

rainfall was used to estimate soil moisture for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS's) runoff curve number were made to estimate direct runoff from each storm event (see appendix A for additional information).

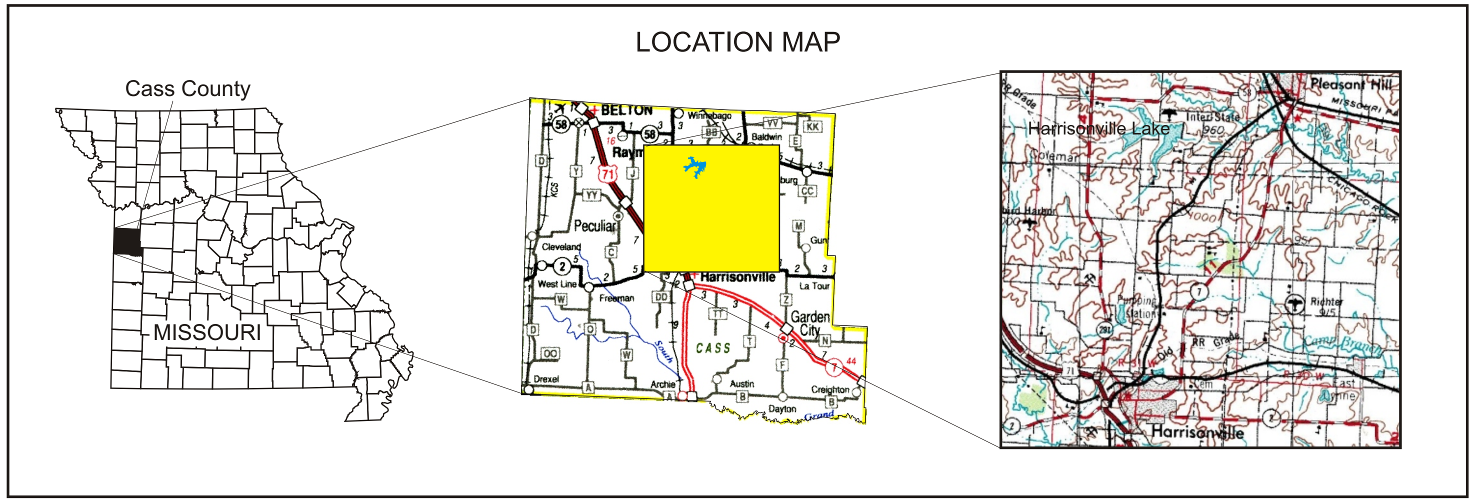
[EVAP.]

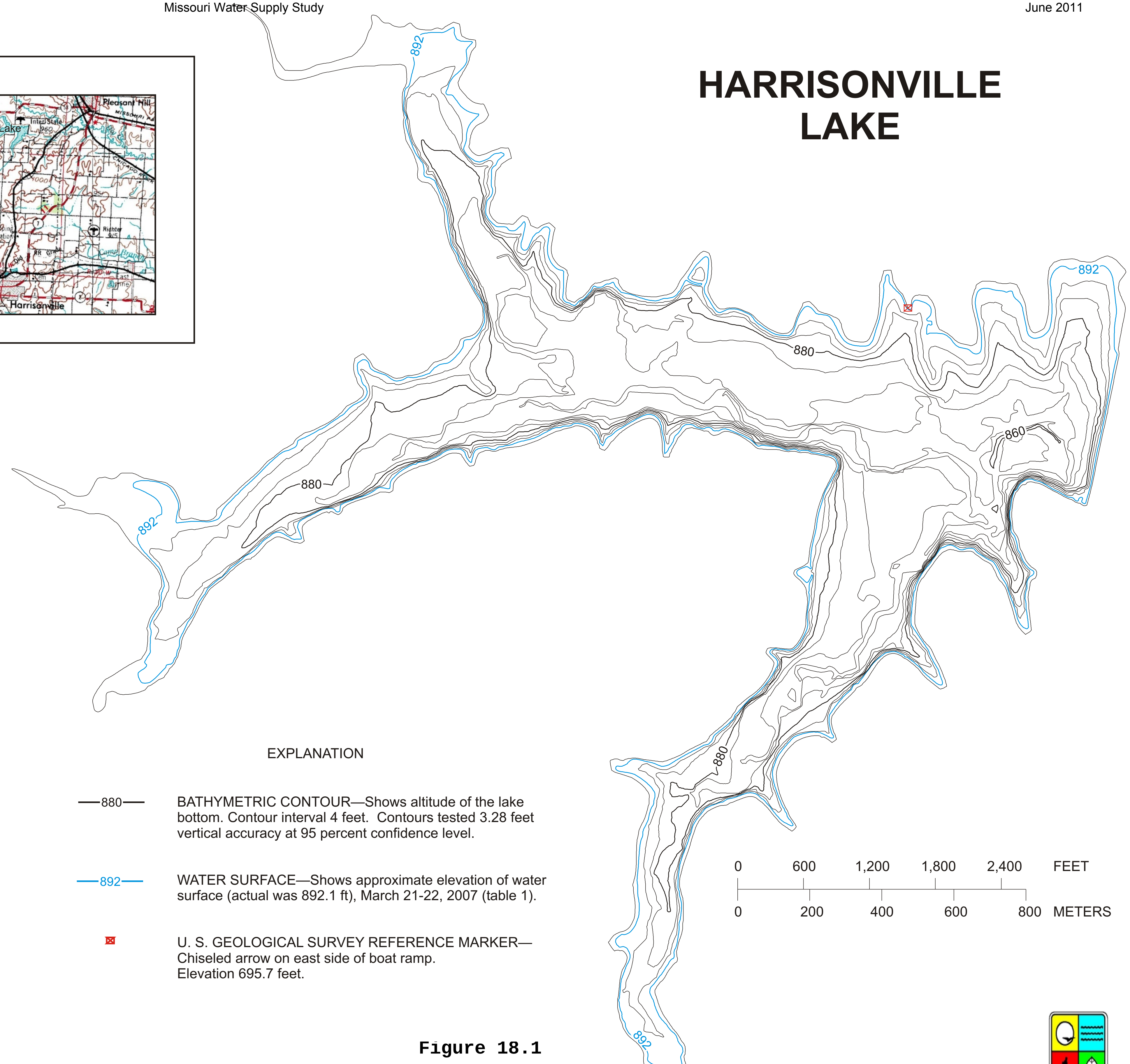
Pan evaporation data from Lakeside gauging station (near the Lake of the Ozarks) was used to estimate water loss from Harrisonville Reservoir due to evaporation. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation values.

[DEMAND]

Water demand was obtained from records submitted to Missouri Department of Natural Resources "Major Water Users Data Base" Harrisonville. Their water use has been steadily increasing since 1954. For this evaluation of 1.4 million gallons per day was assumed. During the period 1994 through 2003 demand steadily increased an average of 25,000 gallons per day.

HARRISONVILLE LAKE





Elevation (feet)	Area (acres)	Volume (acre-ft)
860.0	0.5	0.3
864.0	10.1	16.0
868.0	39.1	110
872.0	105	381
876.0	177	954
880.0	229	1,770
884.0	280	2,780
888.0	325	4,000
892.0	377	5,390
896.0	427	6,990

Table 18.1 Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 896 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.58 feet vertical accuracy at 95 percent confidence level.

EXPLANATION

—880— BATHYMETRIC CONTOUR—Shows altitude of the lake bottom. Contour interval 4 feet. Contours tested 3.28 feet vertical accuracy at 95 percent confidence level.

—892— WATER SURFACE—Shows approximate elevation of water surface (actual was 892.1 ft), March 21-22, 2007 (table 1).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on east side of boat ramp. Elevation 695.7 feet.

Figure 18.1

USGS
science for a changing world

Figure 18.1 Bathymetric map and table of areas/volumes of Harrisonville Lake near Harrisonville and Pleasant Hill, Missouri.

In cooperation with Missouri Department of Natural Resources

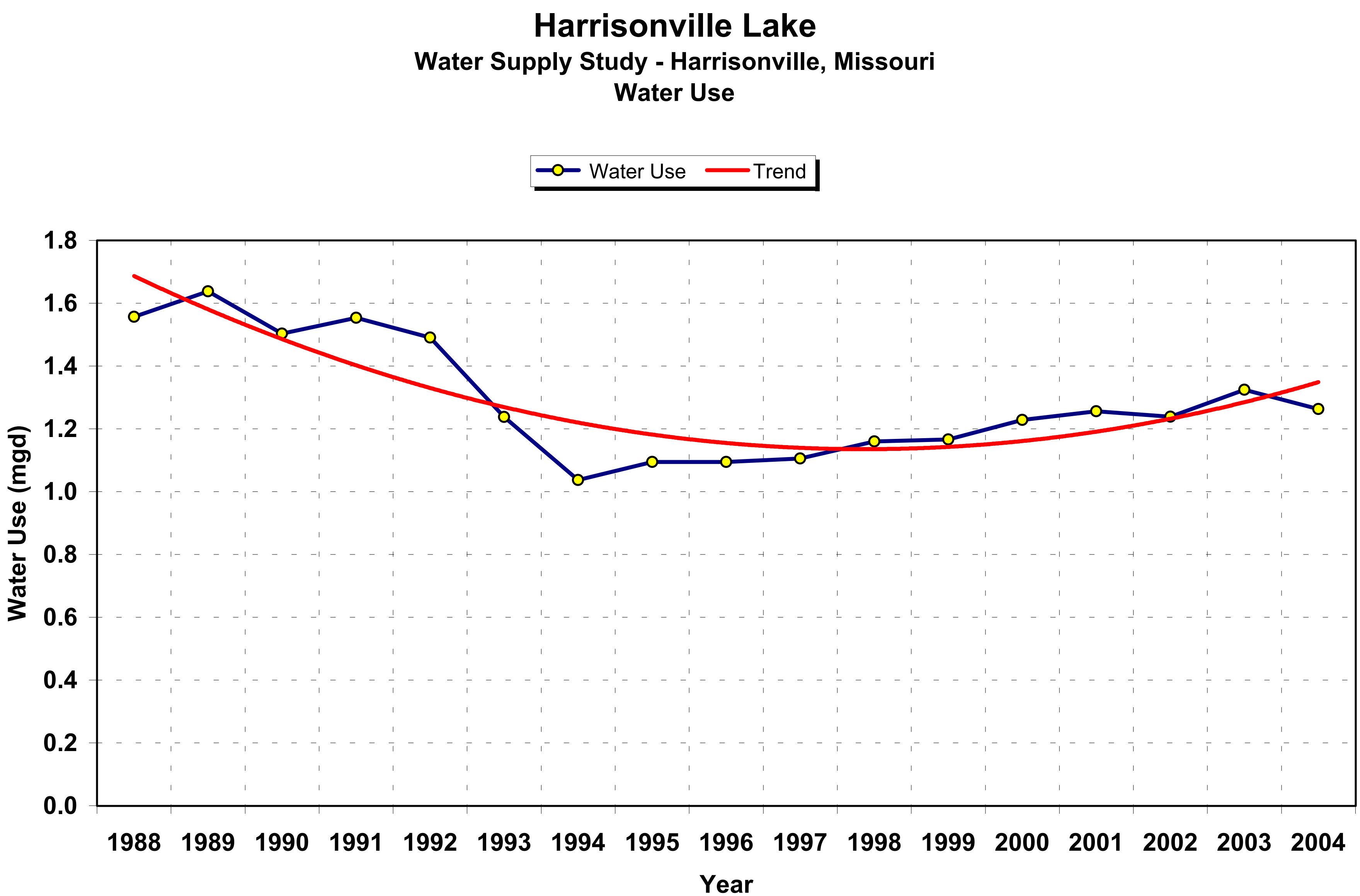

Harrisonville Lake
Water Supply Study - Harrisonville, Missouri
Water Use
Water Use
Trend
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Water Use (mgd)
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Year

Figure 18.2

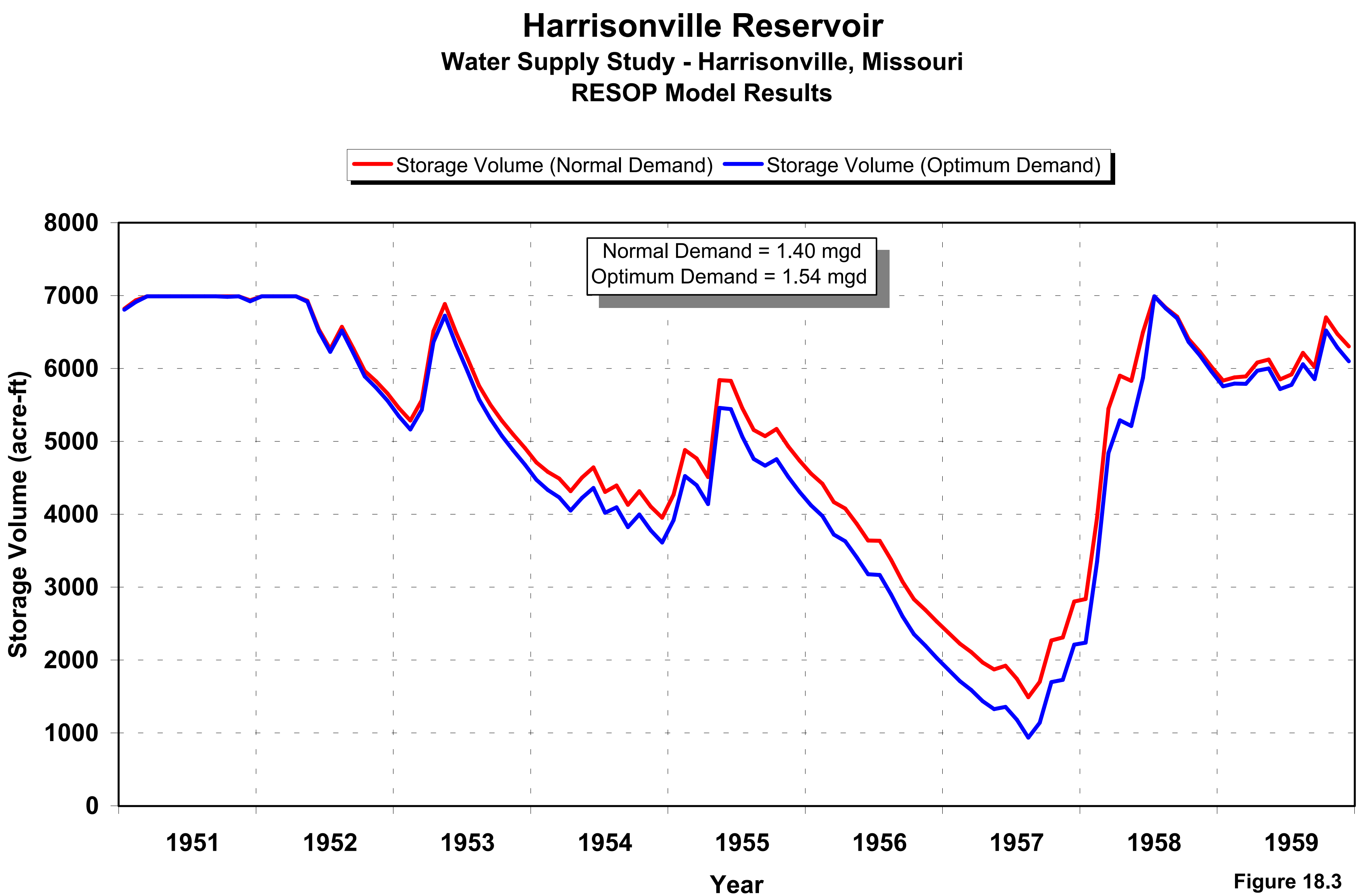

Harrisonville Reservoir
Water Supply Study - Harrisonville, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 1.40 mgd
Optimum Demand = 1.54 mgd
8000
7000
6000
5000
4000
3000
2000
1000
0
Storage Volume (acre-ft)
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 18.3

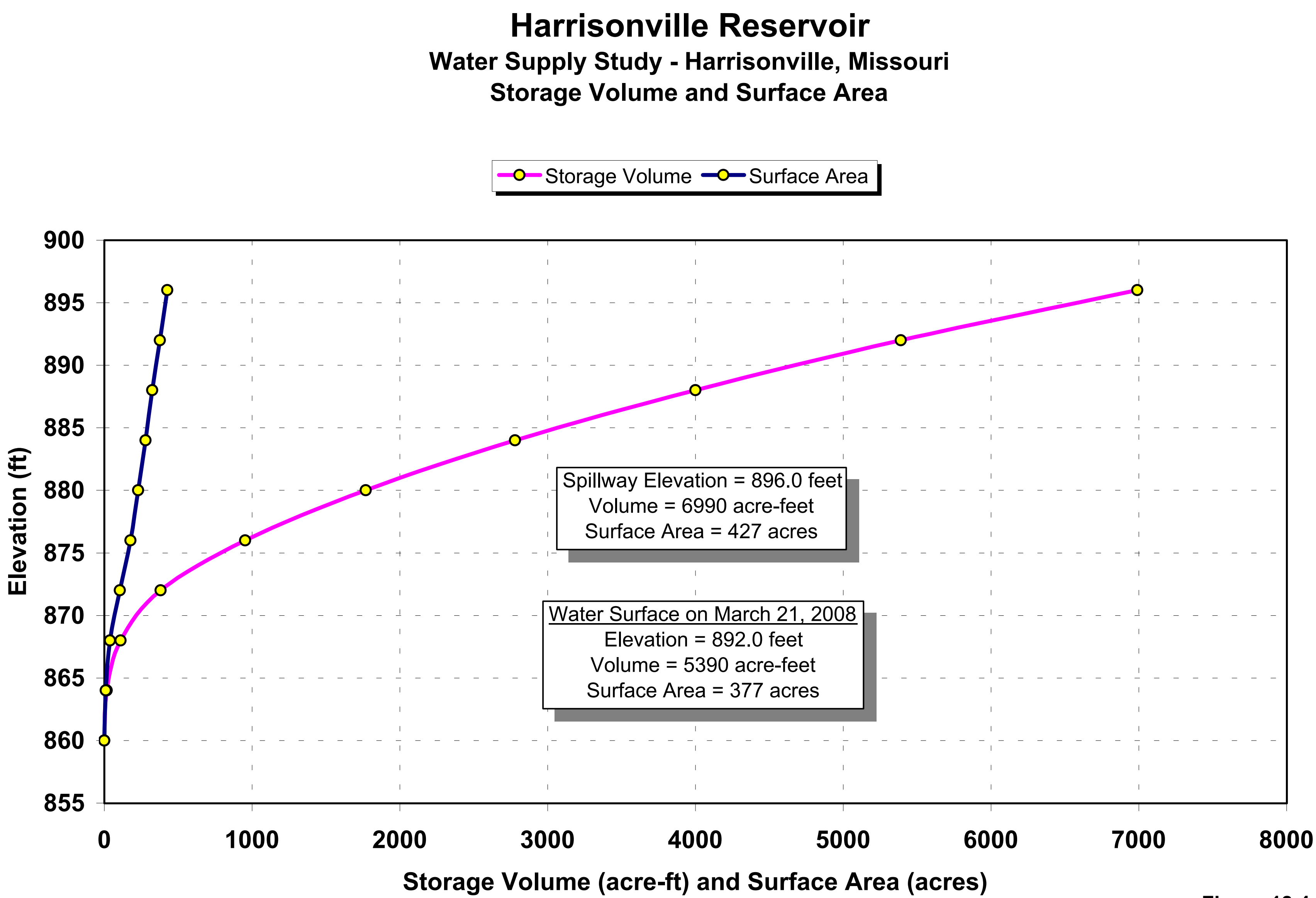

Harrisonville Reservoir
Water Supply Study - Harrisonville, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
900
895
890
885
880
875
870
865
860
855
Elevation (ft)
Spillway Elevation = 896.0 feet
Volume = 6990 acre-feet
Surface Area = 427 acres
Water Surface on March 21, 2008
Elevation = 892.0 feet
Volume = 5390 acre-feet
Surface Area = 377 acres
0
1000
2000
3000
4000
5000
6000
7000
8000
Storage Volume (acre-ft) and Surface Area (acres)

Figure 18.4

Higginsville Reservoir
Water Supply Study – Higginsville, Missouri
Drought Assessment

I. Overview

The Higginsville reservoir system (figures 19.1) is located two miles east of the City of Higginsville on a tributary to Davis Creek in central Lafayette County, Missouri. The reservoir system is the primary source of drinking water for the City of Higginsville, Alma, Corder, Mayview and Laf/Jo/Saline County PWSD (Public Water Supply District) # 2, who purchases their drinking water from Higginsville. The combined population served by the Higginsville reservoir system is approximately 4,700 with an average consumption of 0.857 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

The Higginsville reservoir system consists of a lower (primary) lake and a small upper lake that serves as a sediment control basin for Higginsville Lake. The Higginsville Reservoir system has been supplemented with water diverted from the Missouri River. Water can be diverted from the Missouri River with a pump rated at 1200 gallons per minute. Demand on the Higginsville Reservoir in 2000 was approximately 0.924 million gallons per day. The calculated optimum yield from the reservoir is only 0.456 million gallons per day. To meet the demand of 0.924 million gallons per day, raw water is pumped from the Missouri River into the reservoir. Historical water demand on the Higginsville Reservoir is illustrated in figure 19.2.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Two scenarios were analyzed for the Higginsville reservoir system using the RESOP model:

1. The first scenario assesses the water budget for the reservoir with no additional sources of water (no diversion from the Missouri River). An analysis of 'Normal' demand (actual demand from 2000) was applied to the reservoir during the drought of record to assess potential water deficits. A second analysis for 'Optimum' demand was performed to determine the firm yield from the reservoir without additional water sources - this value represents the viable quantity of water available. Figure 19.3.a illustrates the relationship between these two results. When actual demand is applied to this scenario the reservoir is completely emptied and is not capable of supplying water to meet demand. The firm yield is insufficient to meet demand.

2. The second scenario analyzes 'Normal' demand for the Higginsville reservoir system when additional water is pumped to the reservoir from the Missouri River (figure 19.3.b). It was determined that water diverted from the Missouri River to the reservoir would allow Higginsville to meet the 2000 demand of 0.924 million gallons per day. Higginsville Reservoir is estimated to be capable of meeting this demand with the water level in Higginsville Lake remaining above 1000 acre-feet of storage. Pumping is continuous when the water level is between one and three feet below the spillway. The optimum yield, diverting the same volume of water from the Missouri River, was calculated to be 1.31 million gallons per day (figure 19.3.b). Figure 19.5 illustrates the annual volume of water that would be required for diversion from the Missouri River during the evaluation period.

Figure 19.3.c illustrates the degree of water loss due to evaporation and seepage from the sediment control basin.

II. Drought Assessment Summary

The Higginsville reservoir system without additional sources of water is not sufficient to meet demand. The 2000 demand of 0.924 million gallons per day, when applied to the reservoir during the drought of record (with no additional sources of water) would have resulted in water deficits from 1954 through 1958. The estimated firm yield from the Higginsville reservoir system without supplementary supplies is 0.456 million gallons per day.

The Higginsville Reservoir system is capable of meeting and exceeding the 2000 demand of 0.924 million gallons per day with additional water diverted to the reservoir from the Missouri River. The 2000 demand of 0.924 million gallons per day can be met but water must be diverted from the Missouri River. Actual diversion of water from the Missouri River in 2001 averaged 0.81 million gallons per day, in 1989 an average of 0.789 million gallons per day was diverted.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Higginsville Reservoir conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on June 25, 2002. Surface area of the lake and associated storage volume capacities are illustrated in figure 19.4.a and 19.4.b.

Higginsville Lake Physical Data

Higginsville Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
736.0	3.3	1.8	
738.0	14.0	18.4	
740.0	30.4	62.3	
742.0	47.2	139.8	
744.0	67.8	254.8	
746.0	83.9	407.5	
748.0	98.6	589.9	
750.0	114.8	803.1	
752.0	129.3	1,048.1	
754.0	140.8	1,318.1	
754.7	145.2	1,418.1	Lake Conditions on June 25, 2002
755.0	147.1	1,462.0	Spillway

Upper Lake (Sediment Control Basin)			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
758.0	9.1	4.3	
760.0	22.4	37.7	
762.0	32.2	94.1	
762.8	34.5	120.8	Lake Conditions June 26, 2002
763.0	34.9	127.7	Spillway

[LIMITS]

Higginsville (Primary) Lake
Maximum storage....................1,462.0 acre-feet
Minimum storage....................50.0 acre-feet
Drainage basin size....................2.66 square miles

Upper Lake (Sediment Control Basin)
Maximum storage....................127.7 acre-feet
Minimum storage....................0 acre-feet
Drainage basin size....................2.70 square miles

Combined drainage basin size....................5.36 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity for both lakes.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from the primary lake was estimated to be 2.0 inches per month when the reservoir is at or near full capacity and 0.0 inches per month as the water level approaches the lower limits of the pool. The earthen dam on the Higginsville Reservoir is composed primarily of clay-rich materials and seepage through the dam is minimal.

Seepage for the sediment control basin is minimal and assumed to drain directly into the primary lake. A seepage rate of 0.2 inches per month was used for the upper lake when the lake is at maximum capacity and 0.0 inches when near empty.

[RAINFALL]

Precipitation rates from Lexington, Missouri (approximately 10 miles northwest of Higginsville) were used for this analysis. Average annual precipitation in Lexington is 37.2 inches. Annual precipitation in Lexington from 1953 through 1957 was 24.1 inches, 33.6 inches, 39.4 inches, 25.6 inches, and 47.1 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Blackwater River stream gauge at Blue Lick for the period 1951 through 1954 and 1970 through 2000, South Fork Blackwater River near Elm for 1954 to 1979.

When this regional runoff value is inconsistent with precipitation values recorded for Lexington, individual storm events were considered. Antecedent rainfall was determined for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Higginsville Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at New Franklin, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to derive this value.

[DEMAND]

Water demand for this analysis was the 2000 use. Water demand in 2000 was 0.924 million gallons per day, determined from information maintained in the Missouri Department of Natural Resources (Major Water Users Data Base). The total use in 2000 was 337,125,000 gallons.

[OTHER]

Other refers to water gained or lost from other sources; in this case it is the amount of water pumped to the reservoir from the Missouri River.

HIGGINSVILLE LAKE

EXPLANATION

— 760— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

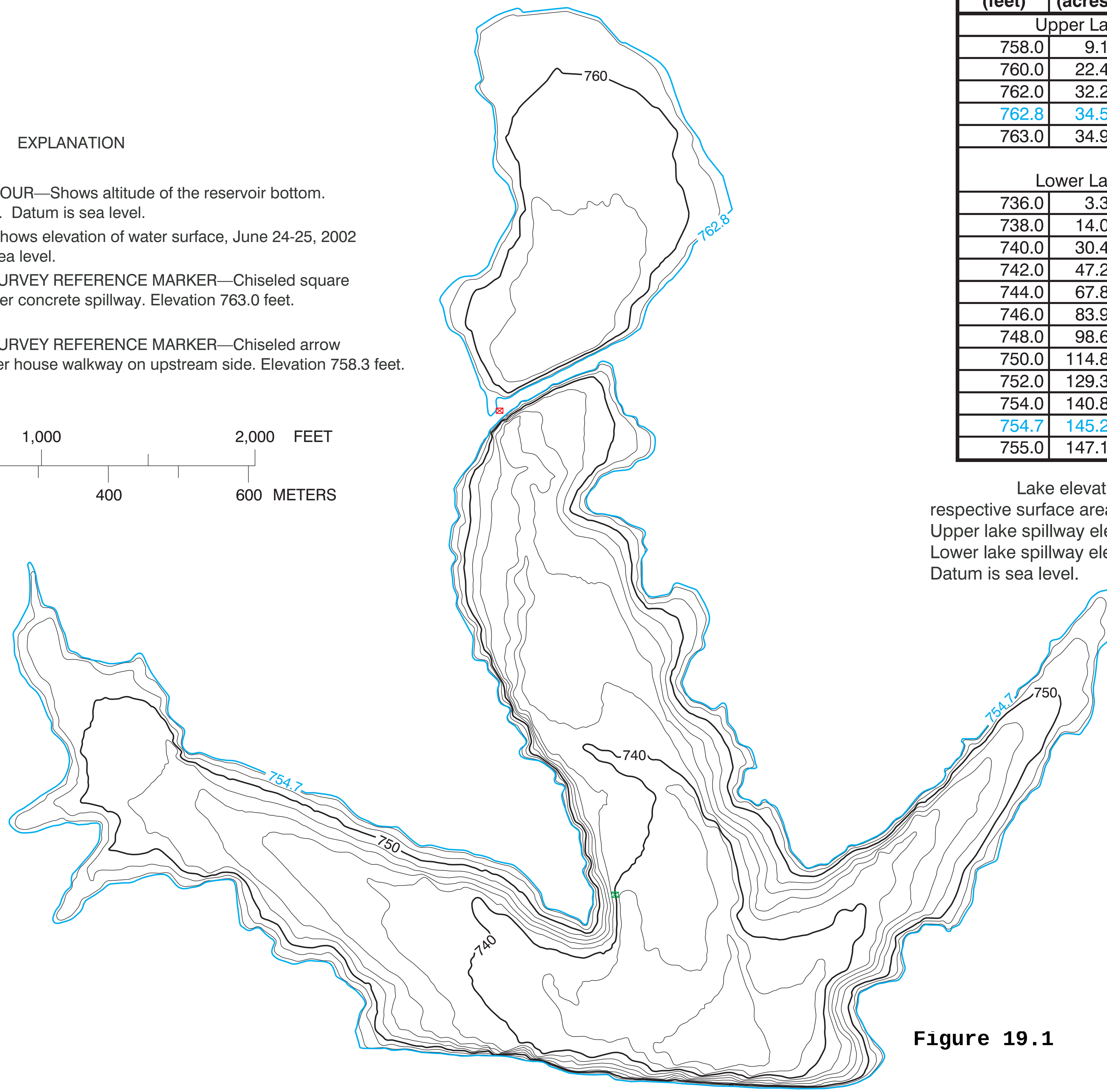
—762.8— WATER SURFACE—Shows elevation of water surface, June 24-25, 2002 (table 19). Datum is sea level.

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square on left overflow of upper concrete spillway. Elevation 763.0 feet. Datum is sea level.

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on second pier of water house walkway on upstream side. Elevation 758.3 feet. Datum is sea level.

0 1,000 2,000 FEET

0 200 400 600 METERS



Elevation (feet)	Area (acres)	Volume (acre-ft)
Upper Lake		
758.0	9.1	4.3
760.0	22.4	37.7
762.0	32.2	94.1
762.8	34.5	120.8
763.0	34.9	127.7
Lower Lake		
736.0	3.3	1.8
738.0	14.0	18.4
740.0	30.4	62.3
742.0	47.2	139.8
744.0	67.8	254.8
746.0	83.9	407.5
748.0	98.6	589.9
750.0	114.8	803.1
752.0	129.3	1,048.1
754.0	140.8	1,318.1
754.7	145.2	1,418.1
755.0	147.1	1,462.0

Lake elevations and respective surface areas and volumes. Upper lake spillway elevation 763.0 feet. Lower lake spillway elevation 755.0 feet. Datum is sea level.

Figure 19.1

Bathymetric map and area/volume table for Higginsville Lake near Higginsville, Missouri.

USGS
science for a changing world

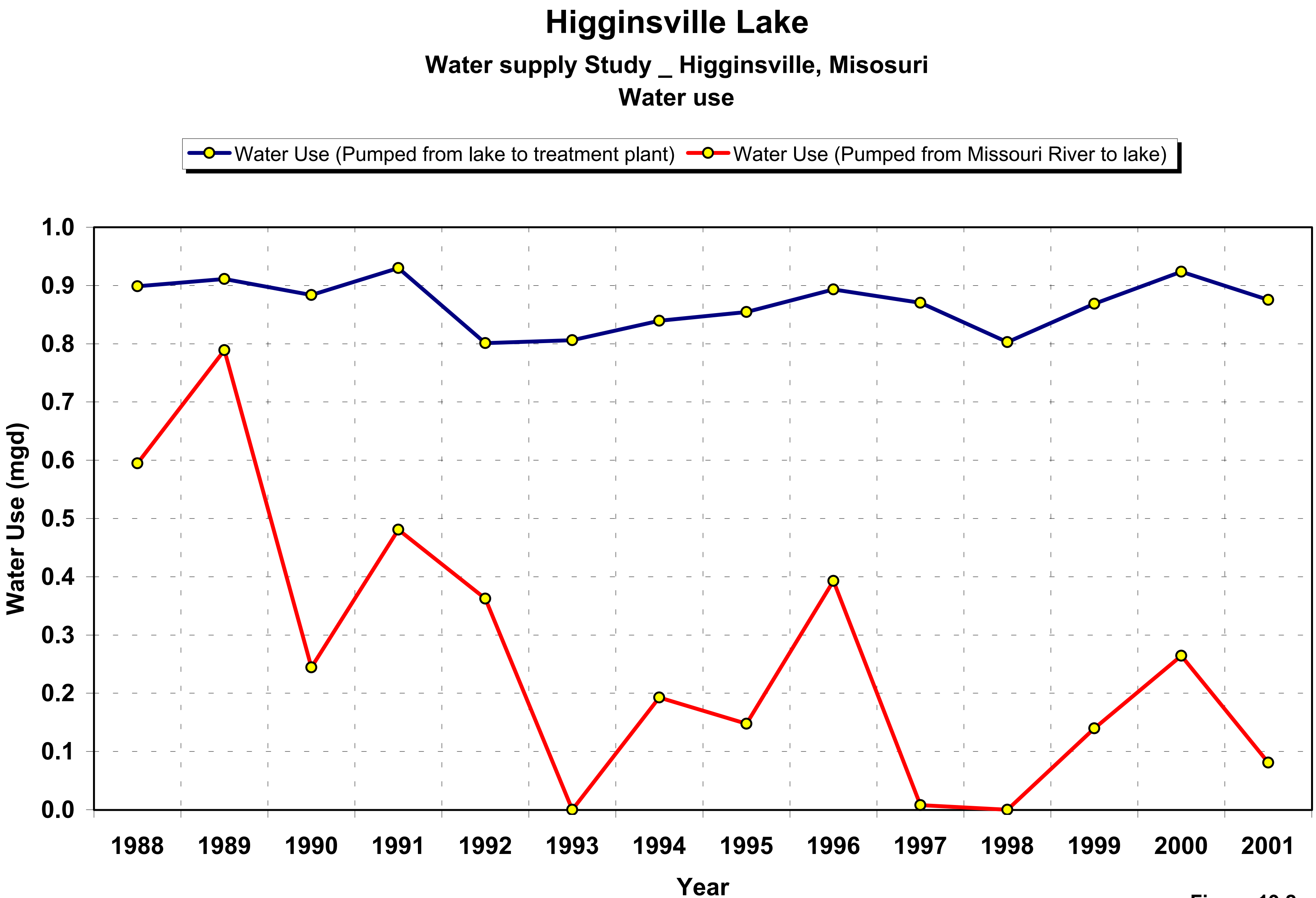

Higginsville Lake
Water supply Study _ Higginsville, Misosuri
Water use
Water Use (Pumped from lake to treatment plant)
Water Use (Pumped from Missouri River to lake)
Water Use (mgd)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 19.2

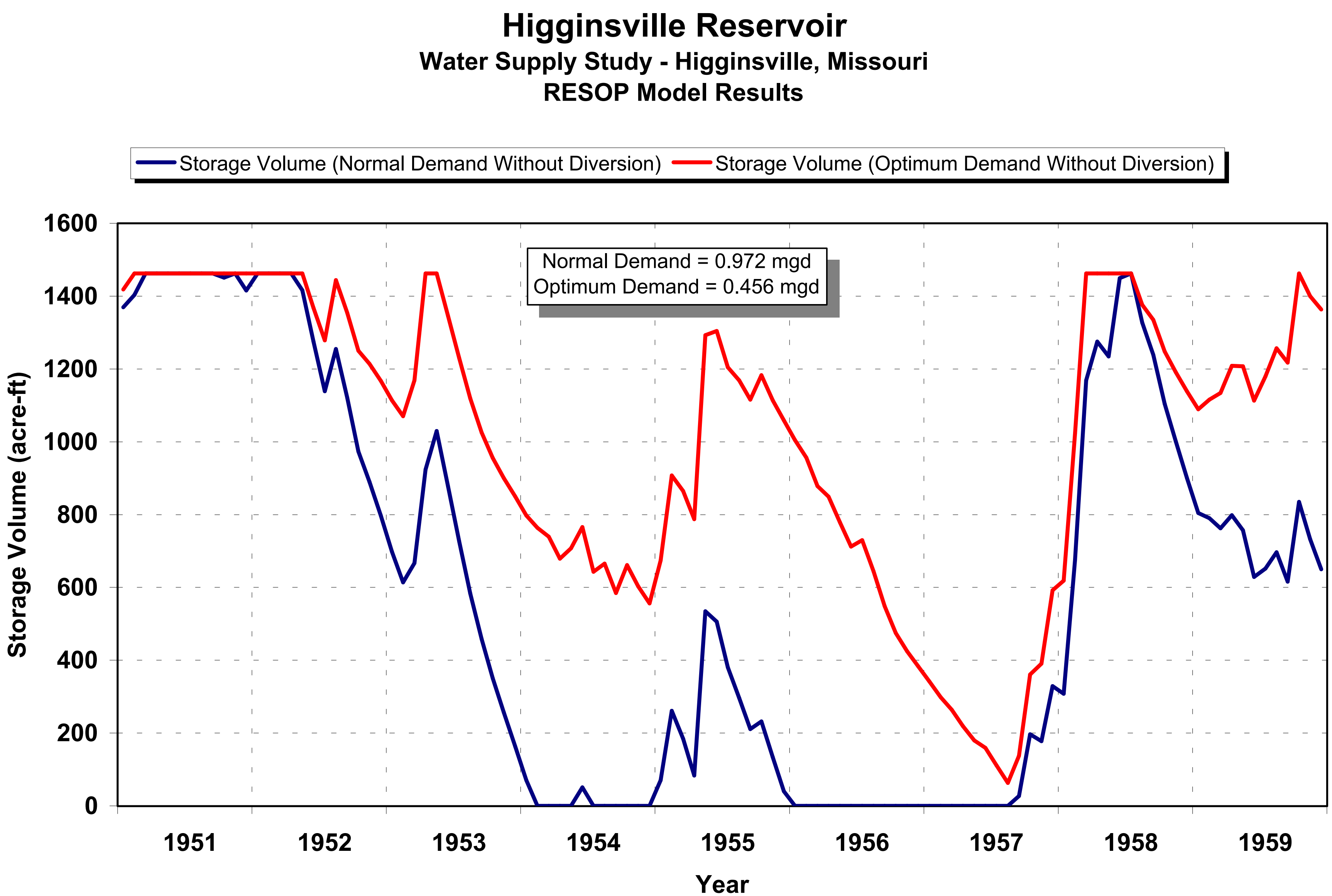

Higginsville Reservoir
Water Supply Study - Higginsville, Missouri
RESOP Model Results
Storage Volume (Normal Demand Without Diversion)
Storage Volume (Optimum Demand Without Diversion)
Normal Demand = 0.972 mgd
Optimum Demand = 0.456 mgd
Storage Volume (acre-ft)
0
200
400
600
800
1000
1200
1400
1600
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 19.3.a

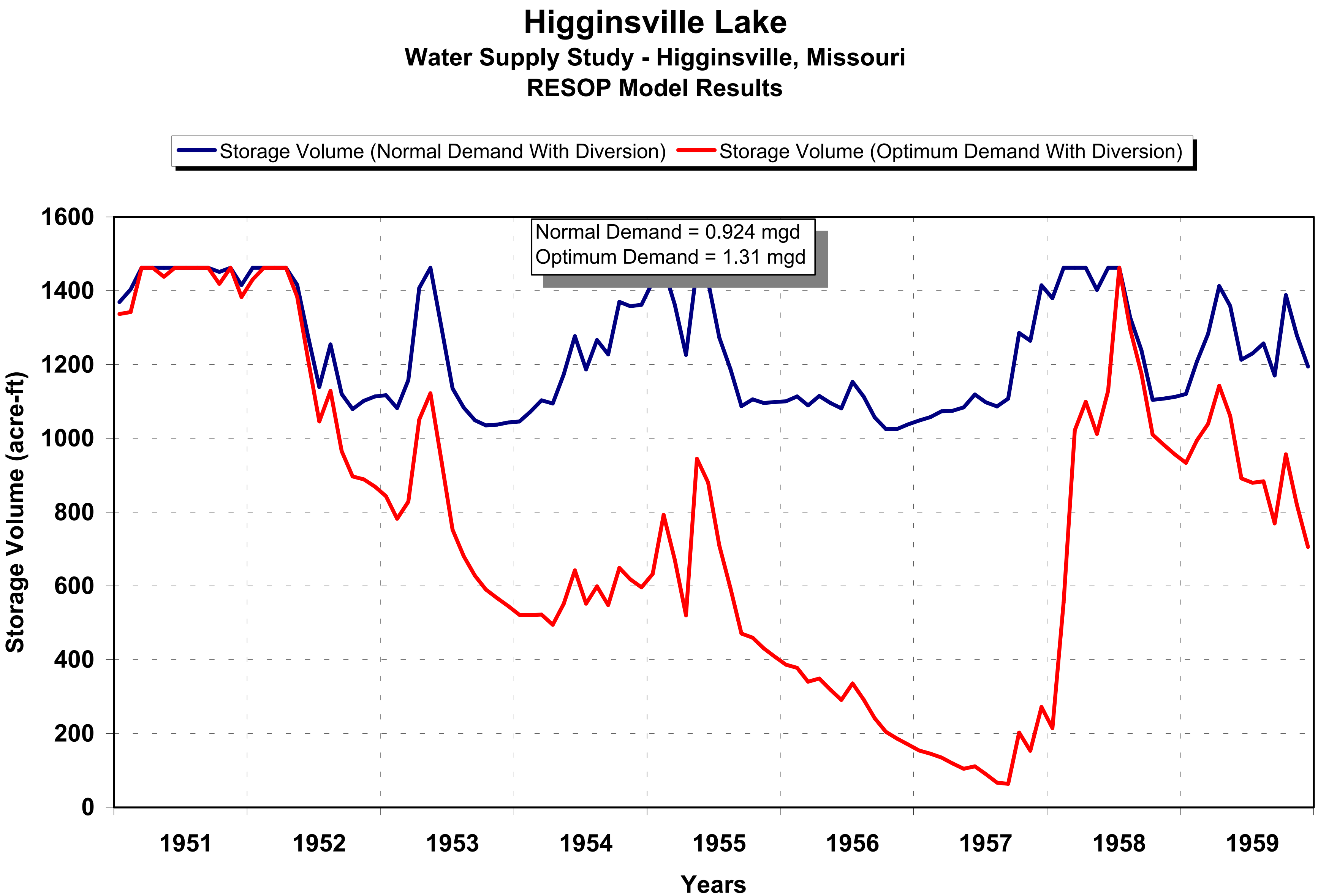

Higginsville Lake
Water Supply Study - Higginsville, Missouri
RESOP Model Results
Storage Volume (Normal Demand With Diversion)
Storage Volume (Optimum Demand With Diversion)
Normal Demand = 0.924 mgd
Optimum Demand = 1.31 mgd
Storage Volume (acre-ft)
1600
1400
1200
1000
800
600
400
200
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 19.3.b

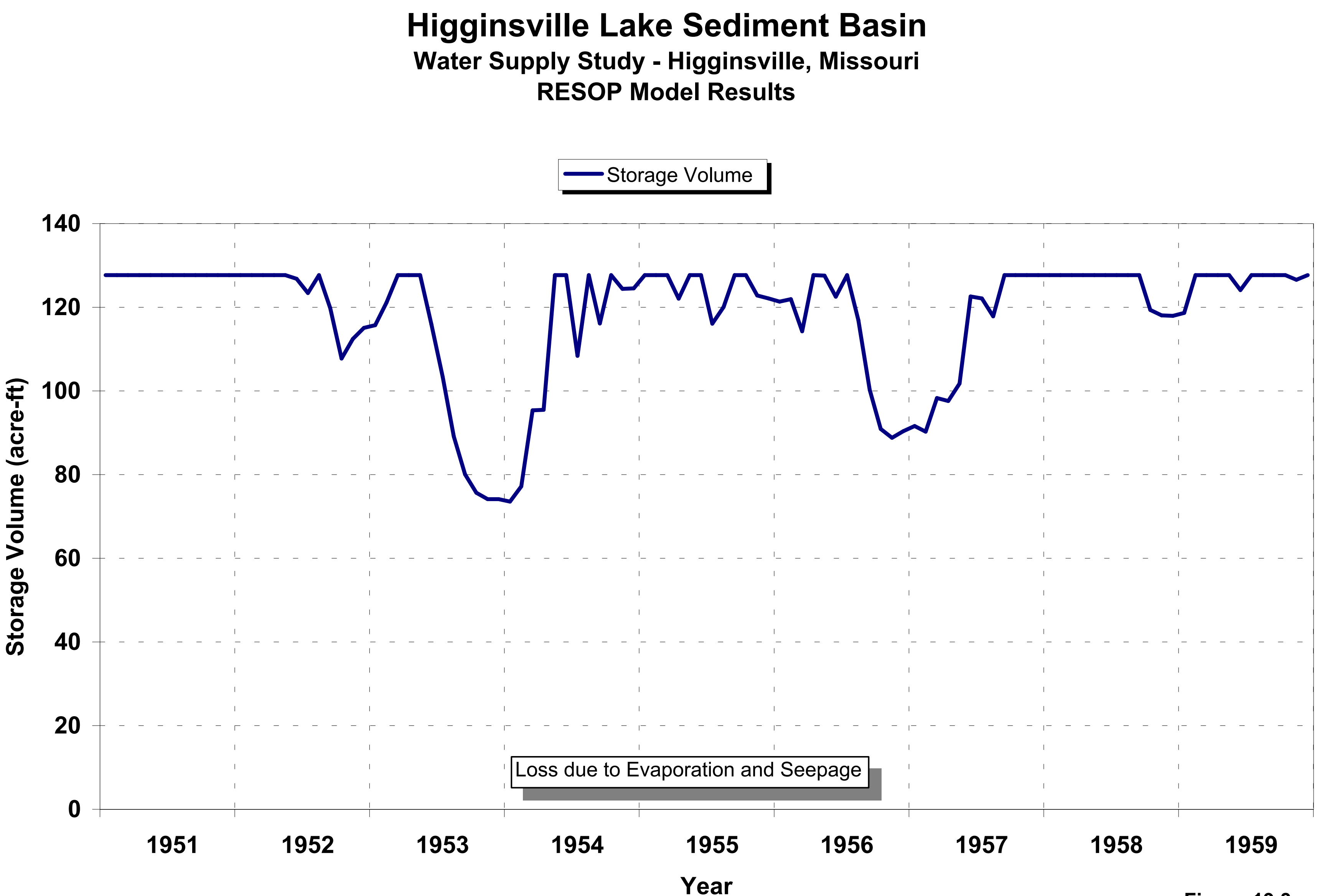

Higginsville Lake Sediment Basin
Water Supply Study - Higginsville, Missouri
RESOP Model Results
Storage Volume
140
120
100
80
60
40
20
0
Storage Volume (acre-ft)
Loss due to Evaporation and Seepage
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 19.3.c

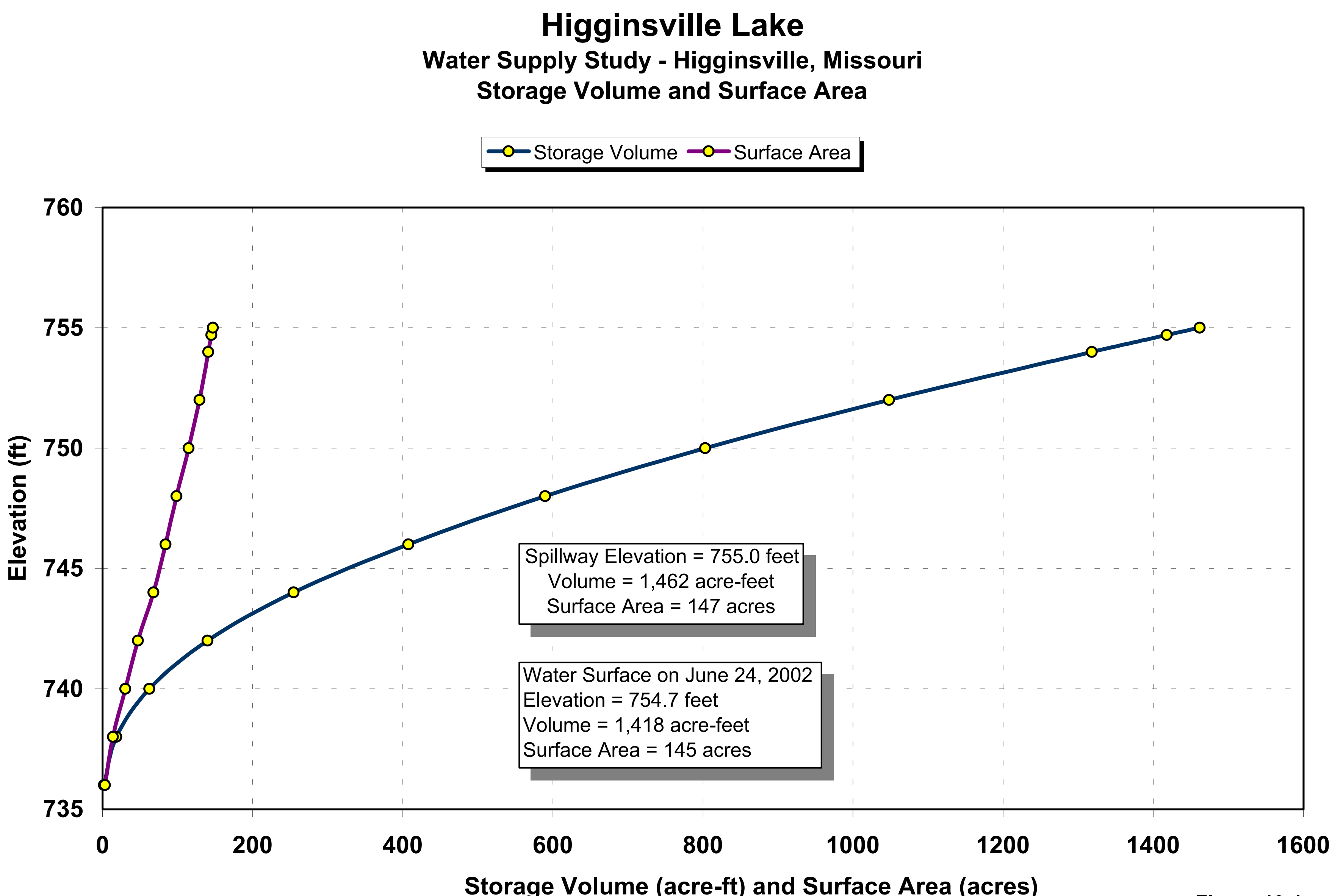

Higginsville Lake
Water Supply Study - Higginsville, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
760
755
750
745
740
735
Elevation (ft)
0
200
400
600
800
1000
1200
1400
1600
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 755.0 feet
Volume = 1,462 acre-feet
Surface Area = 147 acres
Water Surface on June 24, 2002
Elevation = 754.7 feet
Volume = 1,418 acre-feet
Surface Area = 145 acres

Figure 19.4.a

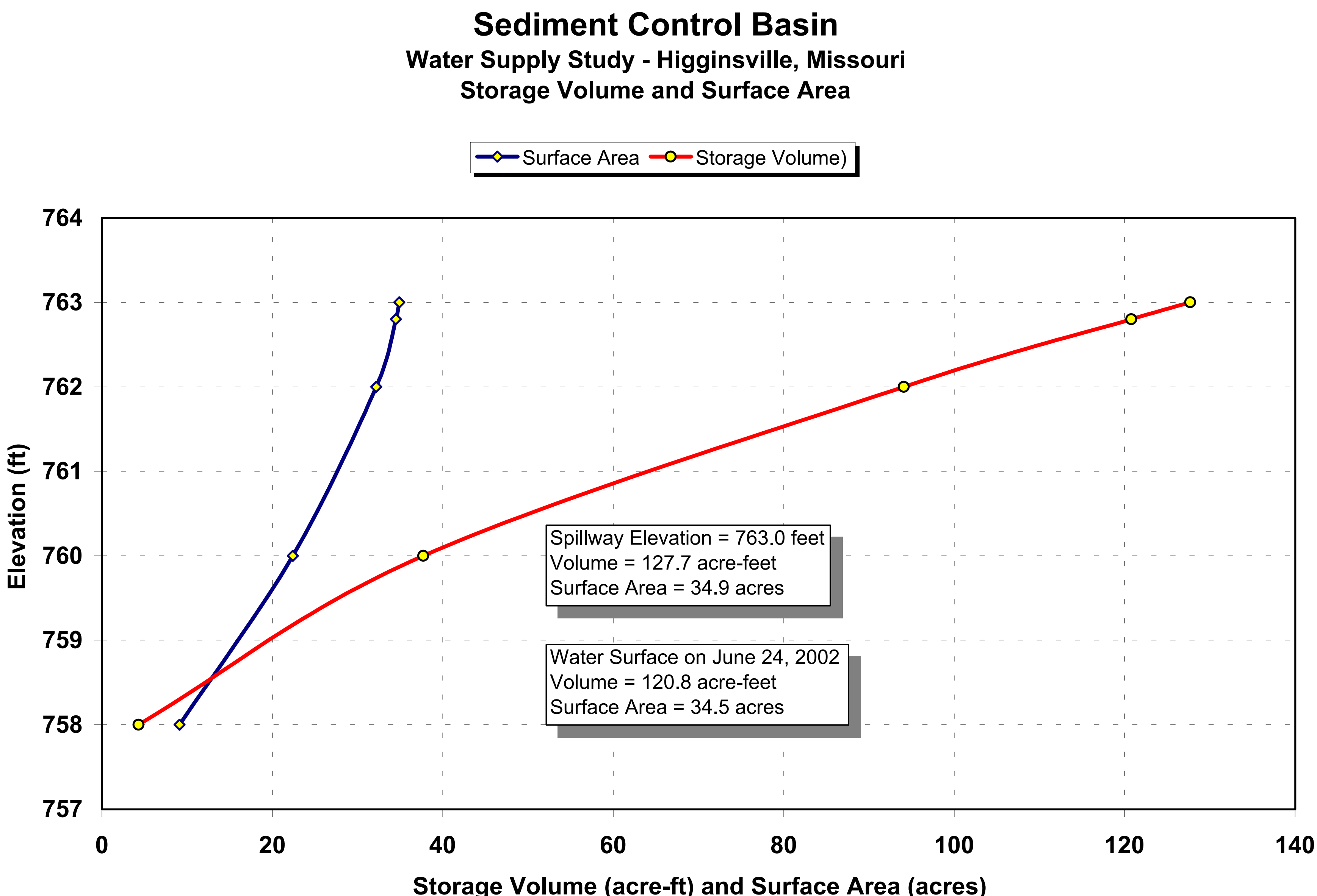

Sediment Control Basin
Water Supply Study - Higginsville, Missouri
Storage Volume and Surface Area
Surface Area
Storage Volume)
764
763
762
761
760
759
758
757
Elevation (ft)
Spillway Elevation = 763.0 feet
Volume = 127.7 acre-feet
Surface Area = 34.9 acres
Water Surface on June 24, 2002
Volume = 120.8 acre-feet
Surface Area = 34.5 acres
0
20
40
60
80
100
120
140
Storage Volume (acre-ft) and Surface Area (acres)

Figure 19.4.b

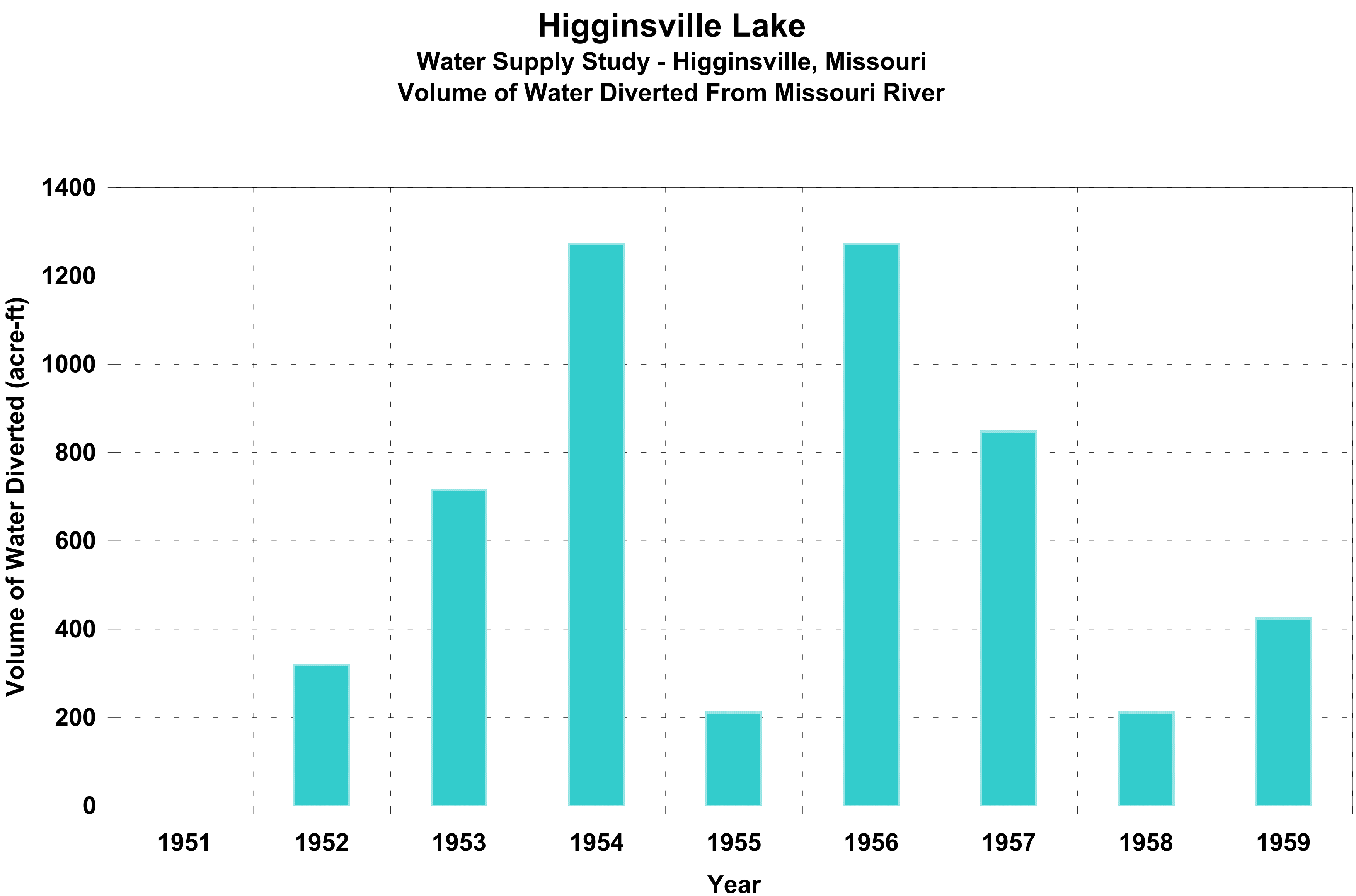

Higginsville Lake
Water Supply Study - Higginsville, Missouri
Volume of Water Diverted From Missouri River
Volume of Water Diverted (acre-ft)
0
200
400
600
800
1000
1200
1400
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 19.5

Holden City Lake
Water Supply Study – Holden, Missouri
Drought Assessment Analysis

Holden City Lake is located in Johnson County Missouri, about four miles Northwest of Holden (figure 20.1). Holden City Lake, Structure A-5 of the NRCS PL-566 watershed project, is located on a tributary to South Fork Blackwater River. Holden City Reservoir serves a population of approximately 2,389 with an estimated water demand of 0.250 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). Holden has not been reporting their water use to the major water users database. The Safe Drinking Water Information System (SDWIS) database reports they are currently using an average of 0.250 million gallon per day.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Holden City Reservoir. The model assumes that ‘Normal’ demand for Holden is 0.25 million gallons per day and by using the volume of the basin allocated to sediment storage, ‘Optimum’ yield from the reservoir is 0.56 million gallons per day. Figure 20.3 illustrates these relationships.

II. Drought Assessment Summary

Holden City Reservoir is capable of supplying Holden’s water needs into the future. The demand on the Holden Reservoir is 0.25 million gallons per day leaving 1300 acre-feet in the reservoir. The estimated optimum yield is 0.56 million gallons per day.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Holden Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on June 2, 2003. Surface area of the lake and associated storage volume capacity are illustrated in figure 20.4.

Holden City Lake Physical Data

Holden Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
802.0	0.07	0.01	
804.0	1.0	0.8	
806.0	3.2	4.9	
808.0	6.2	14	
810.0	10	31	
812.0	17	58	
814.0	26	101	
816.0	36	162	
818.0	47	245	
820.0	58	350	
822.0	74	480	
824.0	90	650	
826.0	105	840	
828.0	124	1,070	
830.0	143	1,340	
832.0	162	1,640	
834.0	184	1,990	
836.0	207	2,380	
837.0	222	2,590	
838.0	237	2,820	
840.0	262	3,320	
841.3	277	3,670	Lake Conditions on June 2, 2003
841.8	292	3,810	Spillway

[LIMITS]

Maximum Storage……………………………………………………………………3810 acre-feet.
Minimum Storage……………………………………………………………………200 acre-feet.
Drainage basin size……………………………………………………………….. 4.02 square miles.

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Holden Lake is approximately 3.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Average precipitation in Holden was 40.0 inches between 1970 and 2000. Precipitation values for the drought of record were obtained from Warrensburg, Missouri (approximately 14 miles northeast of Holden). The most severe drought occurred between 1953 and 1957 with annual

precipitation values in Warrensburg of 25.4 inches, 32.7 inches, 34.7 inches, 21.1 inches, and 40.0 inches, respectively.

Average annual rainfall for the last 50 years is 40.0 inches at Warrensburg. Annual rainfall for 1953 through 1957 is 25.4, 32.7, 34.7, 21.1, and 40.0 inches.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Blackwater River at Blue Lick and South Fork Blackwater River near Elm. The Blackwater River gauge at Blue Lick was used for the period of 1951 through June 1954 when the gauge at South Fork Blackwater began operation. When this regional runoff value is inconsistent with precipitation values recorded for Breckenridge, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

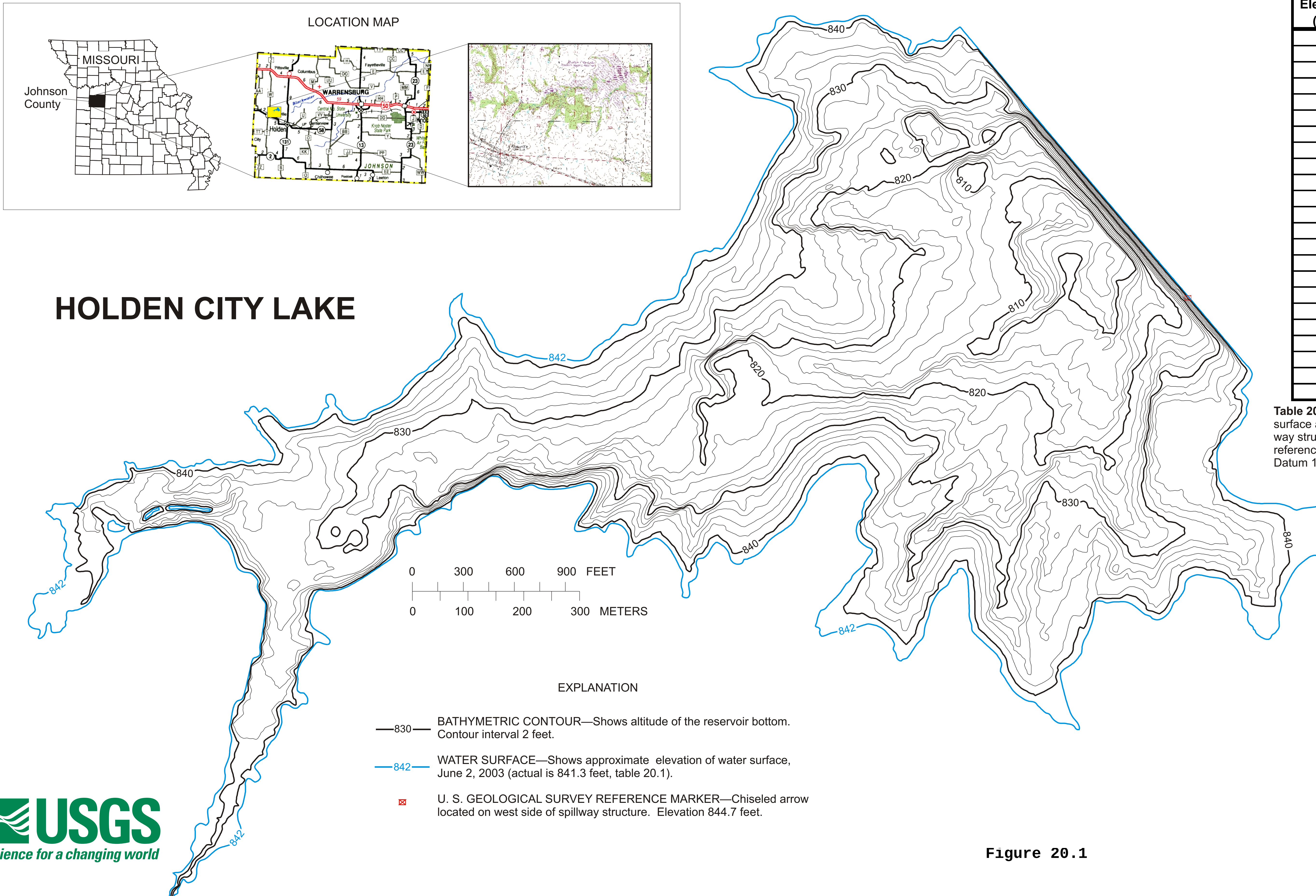
[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Holden City Reservoir due to evaporation. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

Holden has not been reporting their water use because they were not a major water user. This RESOP run was for the daily use recorded in the SDWIS database. The daily amount for this analysis is 0.250 million gallons per day. In the future Holden will be reporting their usage as they now use enough water to be considered a major water user.

HOLDEN CITY LAKE



June 2011

Elevation (feet)	Area (acres)	Volume (acre-ft)
802.0	0.07	0.01
804.0	1.0	0.8
806.0	3.2	4.9
808.0	6.2	14
810.0	10	31
812.0	17	58
814.0	26	101
816.0	36	162
818.0	47	245
820.0	58	350
822.0	74	480
824.0	90	650
826.0	105	840
828.0	124	1,070
830.0	143	1,340
832.0	162	1,640
834.0	184	1,990
836.0	207	2,380
837.0	222	2,590
838.0	237	2,820
840.0	262	3,320
841.3	277	3,670
841.8	292	3,810

Table 20.1 Lake elevations and respective surface areas and volumes. Top of spillway structure is 841.8 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).

EXPLANATION

830 BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

842 WATER SURFACE—Shows approximate elevation of water surface, June 2, 2003 (actual is 841.3 feet, table 20.1).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west side of spillway structure. Elevation 844.7 feet.

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Figure 20.1

Figure 20.1 Bathymetric map and table of areas/volumes of the Holden City Lake near Kingsville, Missouri.

In cooperation with Missouri Department of Natural Resources

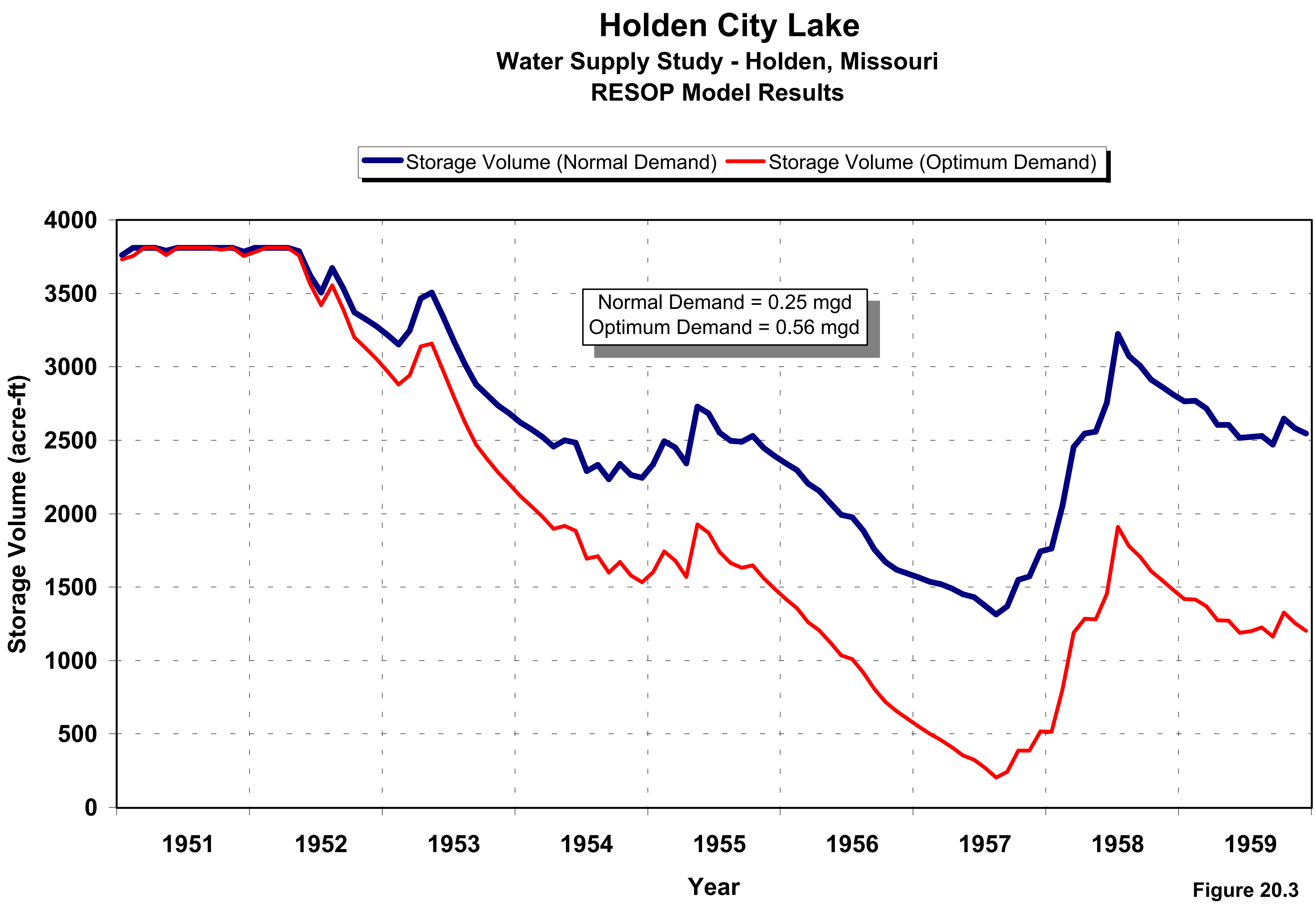

Holden City Lake
Water Supply Study - Holden, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 0.25 mgd
Optimum Demand = 0.56 mgd
Storage Volume (acre-ft)
4000
3500
3000
2500
2000
1500
1000
500
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 20.3

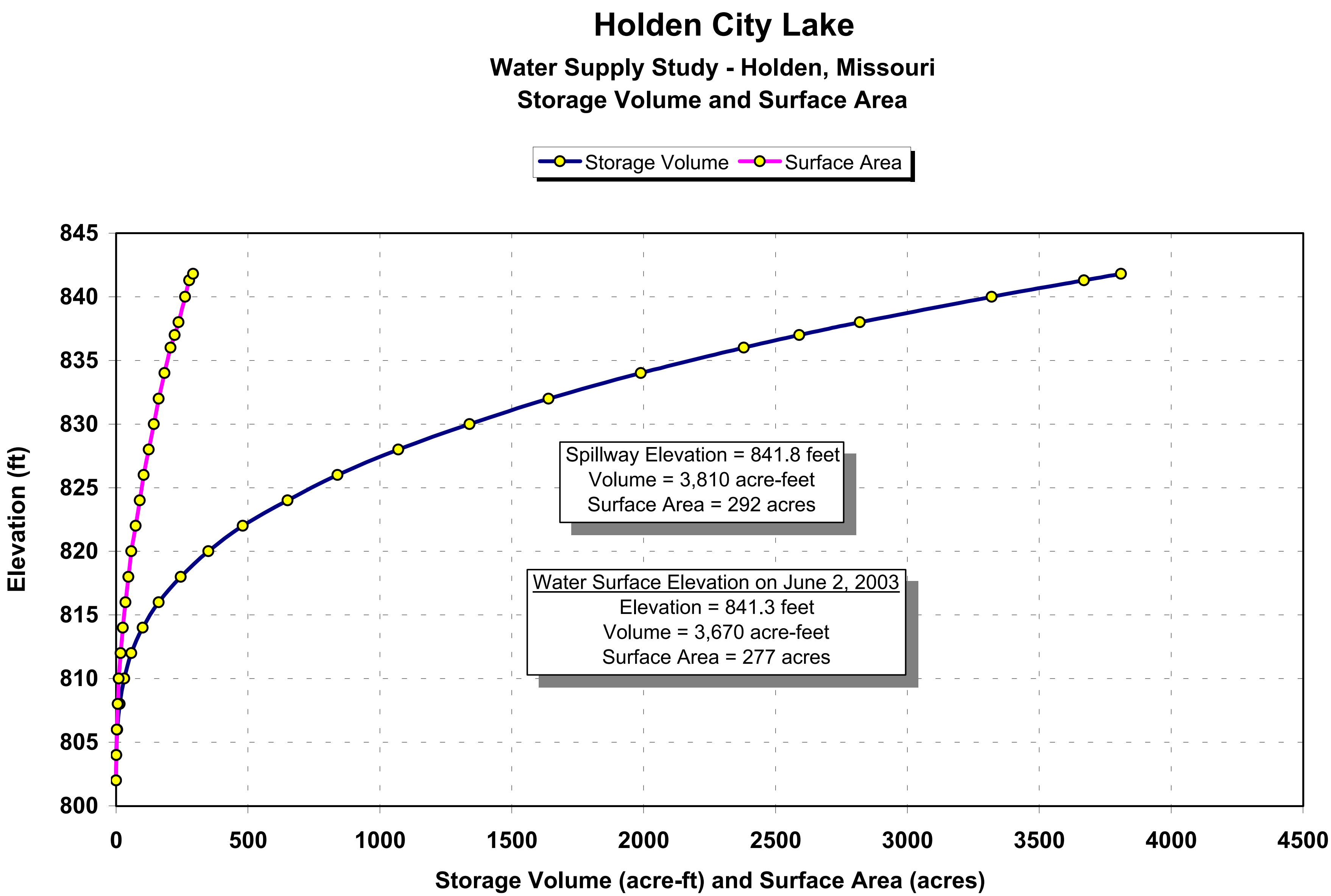

Holden City Lake
Water Supply Study - Holden, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 841.8 feet
Volume = 3,810 acre-feet
Surface Area = 292 acres
Water Surface Elevation on June 2, 2003
Elevation = 841.3 feet
Volume = 3,670 acre-feet
Surface Area = 277 acres
Elevation (ft)
845
840
835
830
825
820
815
810
805
800
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Storage Volume (acre-ft) and Surface Area (acres)

Figure 20.4

Shepherd Mountain Lake and Snowhollow Lake

Water Supply Study - Ironton, Missouri
Drought assessment analysis

I. Overview

Shepherd Mountain Reservoir is located on an unnamed tributary to Stouts Creek in Iron County, in southeast Missouri (figure 21.1.a). Shepherd Mountain Reservoir provides Ironton's water supply. It is located 1.75 miles west south west of Ironton. Upstream is Snowhollow Reservoir (figure 21.1.b), a privately owned lake located 3.7 miles northwest of Ironton. The Shepherd Mountain Reservoir serves a population of approximately 1,700 with an estimated water demand of 0.1698 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). Figure 21.2 demonstrates the historical water use.

Ironton's water supply, Shepherd Mountain Lake, has a drainage area of 3.32 square miles and provides potable water to approximately 1700 residents with 714 service connections. Upstream is Snowhollow Lake, which has a drainage area of 0.78 square miles. The total drainage area is 4.10 square miles. The city has an agreement with the owners of Snowhollow Reservoir to release water to the Shepherd Mountain Lake during periods of severe water shortage. Losses in the upper, Snowhollow Lake, are attributed to evaporation and seepage. Spillage from Snowhollow Reservoir during large rainfall events is added as inflow to the Shepherd Mountain Reservoir. In 2001 Ironton's water needs was approximately 200,000 gallons per day.

Average annual rainfall is 44.5 inches. Approximately two thirds of rainfall occurs from January through July, accounting for 80 percent of the annual water runoff filling Shepherd Mountain Lake. Lake surveys show the Snow Hollow Reservoir contains 321 acre-feet of water and Shepherd Mountain Reservoir has 186 acre-feet.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Shepherd Mountain Reservoir. The model assumes that 'Normal' demand for Ironton is 200,000 gallons per day and that 'Optimum' yield from the lake is 226,000 gallons per day. On analysis of rainfall data, eastern Missouri has not had the extended dry periods that occur in northwest Missouri. The most severe water shortage occurred in 1964, as a result the evaluation period was from 1954 through 1969. Figure 21.3.a illustrates these relationships. Figure 21.3.b illustrates the degree of water loss due to evaporation and seepage from Snowhollow Reservoir.

II. Drought Assessment Summary

The Shepherd Mountain Reservoir is sufficient to meet Ironton's demand. The 2001 demand of 200,000 gallons per day, when applied to the reservoir during the drought of record would have resulted in water being dangerously low in December 1964 when only

33 acre-feet of water remained (figure 21.3.b). It would have been prudent to release water from Snowhollow Reservoir to assure that domestic need be met. The estimated optimum yield from Shepherd Mountain Reservoir was determined to be 226,000 gallons per day.

This analysis demonstrates that Ironton's 2001 water demand on Shepherd Mountain Reservoir could be met during the most critical period of the 1950's and 1960's. The critical period for this water supply study was based on total annual rainfall. The smallest annual rainfall of 18.95 occurred in 1956 but 1960 through 1967 was the longest extended period when rainfall was below average. Examination of the monthly rainfall and runoff shows that 1955 through 1969 had the most rainfall in the spring months and then becomes significantly drier beginning in June. As a result there was spillage from the Shepherd Mountain Lake in the spring and low lake levels in the same year. The result of this analysis indicates there would be 67-acre feet of water remaining in the lake in November 1956 and in December 1964 there would have been 33-acre feet remaining.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO AREA]

Volume and surface area data were derived from bathymetric surveys of Lake Show Me Reservoir and Old Memphis Reservoir. These were conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources for Shepherd Mountain Reservoir and Snowhollow Reservoirs on July 10, 2007. Surface area of the lakes and associated storage volume capacities are illustrated in figure 21.4.a and 21.4.b.

Shepherd Mountain and Snowhollow Reservoirs Physical Data

Shepherd Mountain Reservoir				***Snow Hollow Reservoir***		
Elevation (feet)	Area (acres)	Volume (acre-feet)		Elevation (feet)	Area (acres)	Volume (acre-feet)
952.0	0.0	0.0		1256.0	0.1	0.0
954.0	0.1	0.1		1258.0	0.5	0.5
956.0	0.4	0.5		1260.0	1.3	2.3
958.0	0.9	1.7		1262.0	2.5	6.1
960.0	1.7	4.3		1264.0	3.9	12.5
962.0	2.9	8.9		1266.0	5.4	21.7
964.0	4.5	16.2		1268.0	6.8	34.0
966.0	6.3	26.9		1270.0	8.5	49.3
968.0	8	41.5		1272.0	10	68.2
970.0	11	60.3		1274.0	12	91
972.0	16	85.4		1276.0	15	119
974.0	19	121		1278.0	18	151
976.0	20	161		1280.0	21	189
976.9	21	179		1282.0	26	235
977.2	21	186		1284.0	29	291
				1285.0	31	321

Shepherd Mountain Reservoir Principal Spillway Elevation = 976.9 feet Lake Conditions - July 10, 2007 Elevation = 977.2 feet	Snowhollow Reservoir Spillway Elevation = 1285.0 feet Lake Conditions - July 10, 2007 Elevation = 1285.0 feet

[LIMITS]

Shepherd Mountain Lake
Maximum storage……………………………………………………………186 acre-feet
Minimum storage……………………………………………………………20 acre-feet
Drainage basin size…………………………………………………3.32 square miles

Snowhollow Lake
Maximum Storage…………………………………………………………321 acre-feet
Minimum Pool Storage……………………………………………………..25 acre-feet
Drainage basin size………………………………………………..… 0.78 square miles

Combined drainage area……………………………………………..4.10 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's through the 1960's. The analysis period for this model is January 1951 through December 1969.

[SEEPAGE]

Seepage from Shepherd Mountain and Snowhollow Reservoirs were estimated to be equal at 5.0 inches per month when at or near full capacity and approaches 0.0 inch as the reservoirs are emptied. The reservoirs are bound by an earthen dams composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation values for the drought of record were obtained from Arcadia, Missouri (Located 2 miles south of Ironton).

Average precipitation at Arcadia was 44.5 inches between 1950 and 1996. Rainfall is distributed fairly evenly throughout the year and southeast Missouri does not experience the extended periods of drought as northern Missouri.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Black River stream gauge near Annapolis for the period 1951 through 1954. For the period 1955 through 1969 Barnes Creek near Fredericktown was used. When this regional runoff value is inconsistent with precipitation values recorded for Arcadia, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

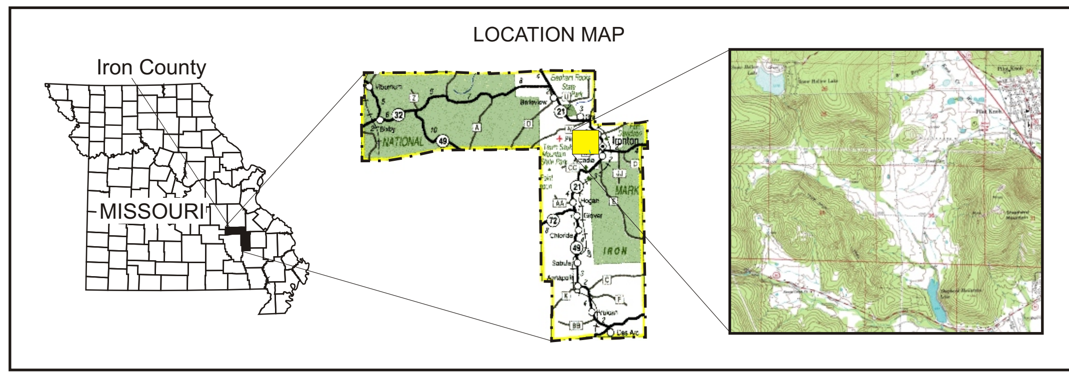
Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Shepherd Mountain and Snowhollow Reservoirs due to evaporation. This data was compared with evaporation data from stations at St. Louis Missouri. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

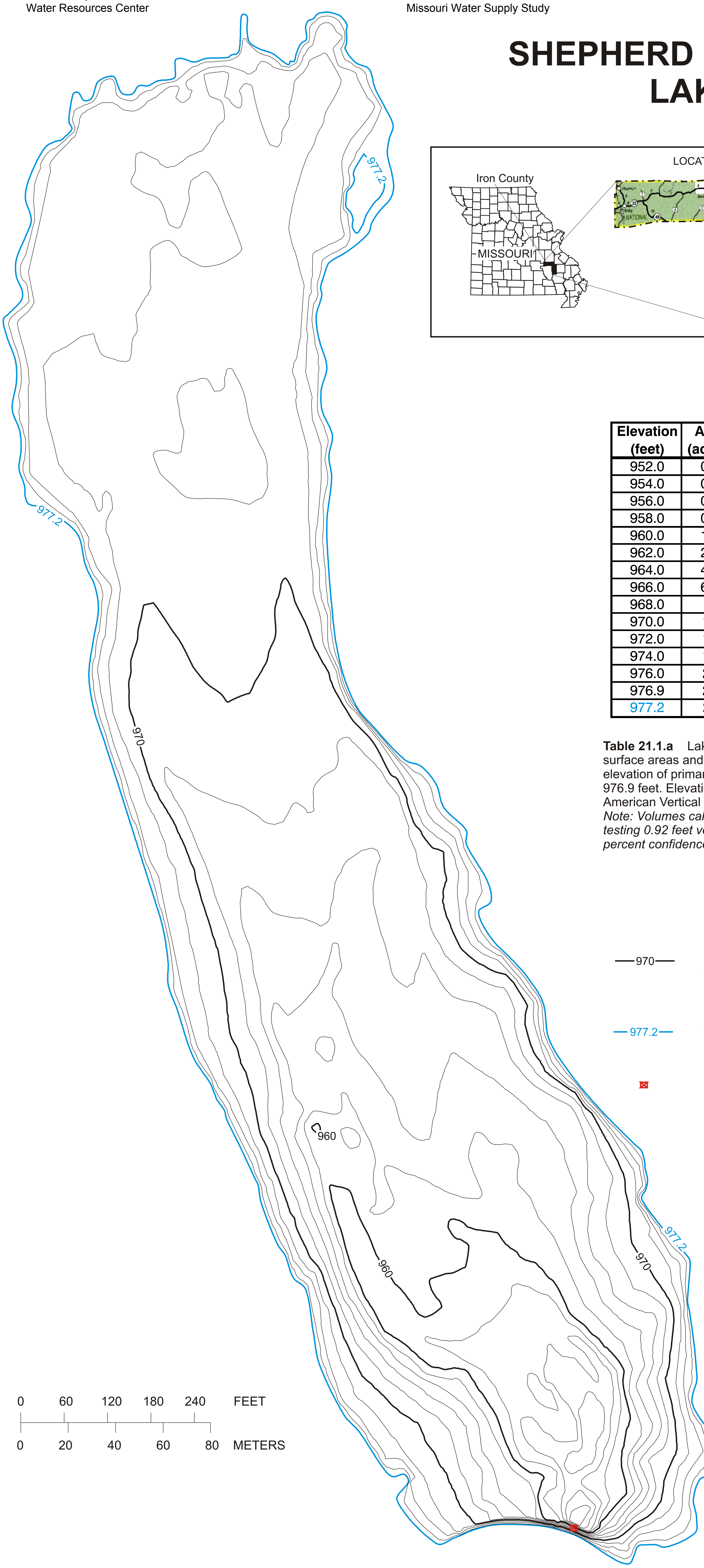
[DEMAND]

Data reported by Ironton to the Missouri major water users database for the period 1989 through 2001 shows the city's water needs in 2001 to be 200,000 gallons per day that is used for this analysis. (Figure 21.2)

Their water use declined to 120,000 gallons per day in 1995 and has been steadily increasing to 200,000 gallons per day in 2001 then fell to 170,000 gallons per day in 2004. For this analysis 200,000 gallons per day was used. It was not necessary to release water from Snowhollow Lake to meet Ironton's demand.

SHEPHERD MOUNTAIN LAKE





Elevation (feet)	Area (acres)	Volume (acre-ft)
952.0	0.0	0.0
954.0	0.1	0.1
956.0	0.4	0.5
958.0	0.9	1.7
960.0	1.7	4.3
962.0	2.9	8.9
964.0	4.5	16.2
966.0	6.3	26.9
968.0	8	41.5
970.0	11	60.3
972.0	16	85.4
974.0	19	121
976.0	20	161
976.9	21	179
977.2	21	186

Table 21.1.a Lake elevations and respective surface areas and volumes. Approximate elevation of primary spillway structure is 976.9 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88). *Note: Volumes calculated from surface testing 0.92 feet vertical accuracy at 95 percent confidence level.*

EXPLANATION

970 BATHYMETRIC CONTOUR—Shows altitude of the lake bottom. Contour interval 2 feet. Contours tested 1.20 feet vertical accuracy at 95 percent confidence level.

977.2 WATER SURFACE—Shows elevation of water surface, July 9-10, 2007 (table 1).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on northeast corner of intake structure. Elevation 982.2 feet.

Figure 21.1.a

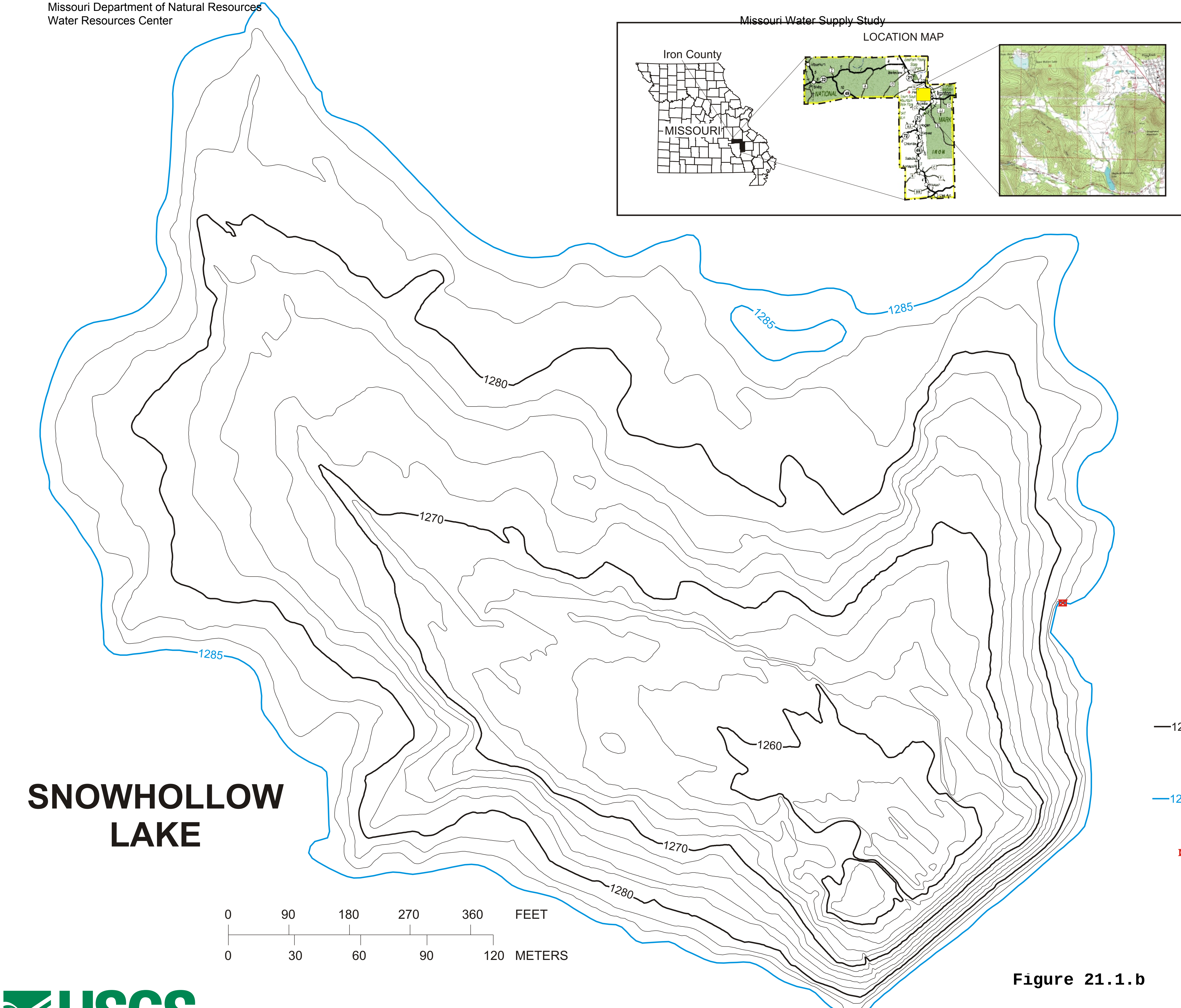
USGS science for a changing world

Figure 21.1.a Bathymetric map and table of areas/volumes of Shepherd Mountain Lake near Ironton, Missouri.

In cooperation with Missouri Department of Natural Resources

Missouri Department of Natural Resources
Water Resources Center

Missouri Water Supply Study



Elevation (feet)	Area (acres)	Volume (acre-ft)
1256.0	0.1	0.0
1258.0	0.5	0.5
1260.0	1.3	2.3
1262.0	2.5	6.1
1264.0	3.9	12.5
1266.0	5.4	21.7
1268.0	6.8	34.0
1270.0	8.5	49.3
1272.0	10	68.2
1274.0	12	91.0
1276.0	15	119
1278.0	18	151
1280.0	21	189
1282.0	26	235
1284.0	29	291
1285.0	31	321

Table 21.1.b Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 1285 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.17 feet vertical accuracy at 95 percent confidence level.

EXPLANATION

—1260— BATHYMETRIC CONTOUR—Shows altitude of the lake bottom. Contour interval 2 feet. Contours tested 1.48 feet vertical accuracy at 95 percent confidence level.

—1285— WATER SURFACE—Shows approximate elevation of water surface (actual was 1285.3 ft), July 10, 2007 (table 1).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on north side of fishing dock. Elevation 1287.1 feet.

Figure 21.1.b

USGS
science for a changing world

Figure 21.1.b Bathymetric map and table of areas/volumes of Snow Hollow Lake near Pilot Knob, Missouri.

In cooperation with Missouri Department of Natural Resources

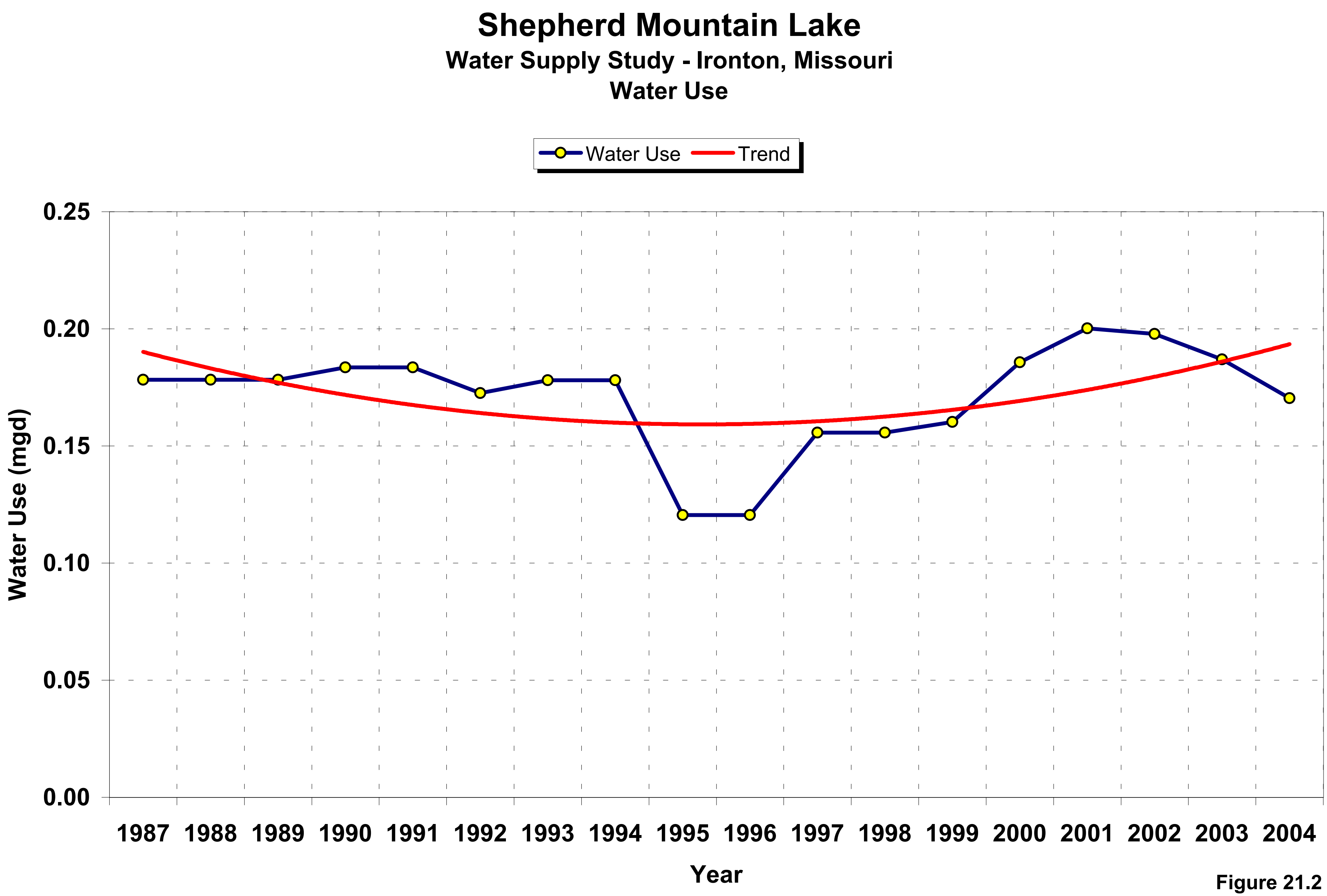

Shepherd Mountain Lake
Water Supply Study - Ironton, Missouri
Water Use
Water Use
Trend
0.25
0.20
0.15
0.10
0.05
0.00
Water Use (mgd)
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Year

Figure 21.2

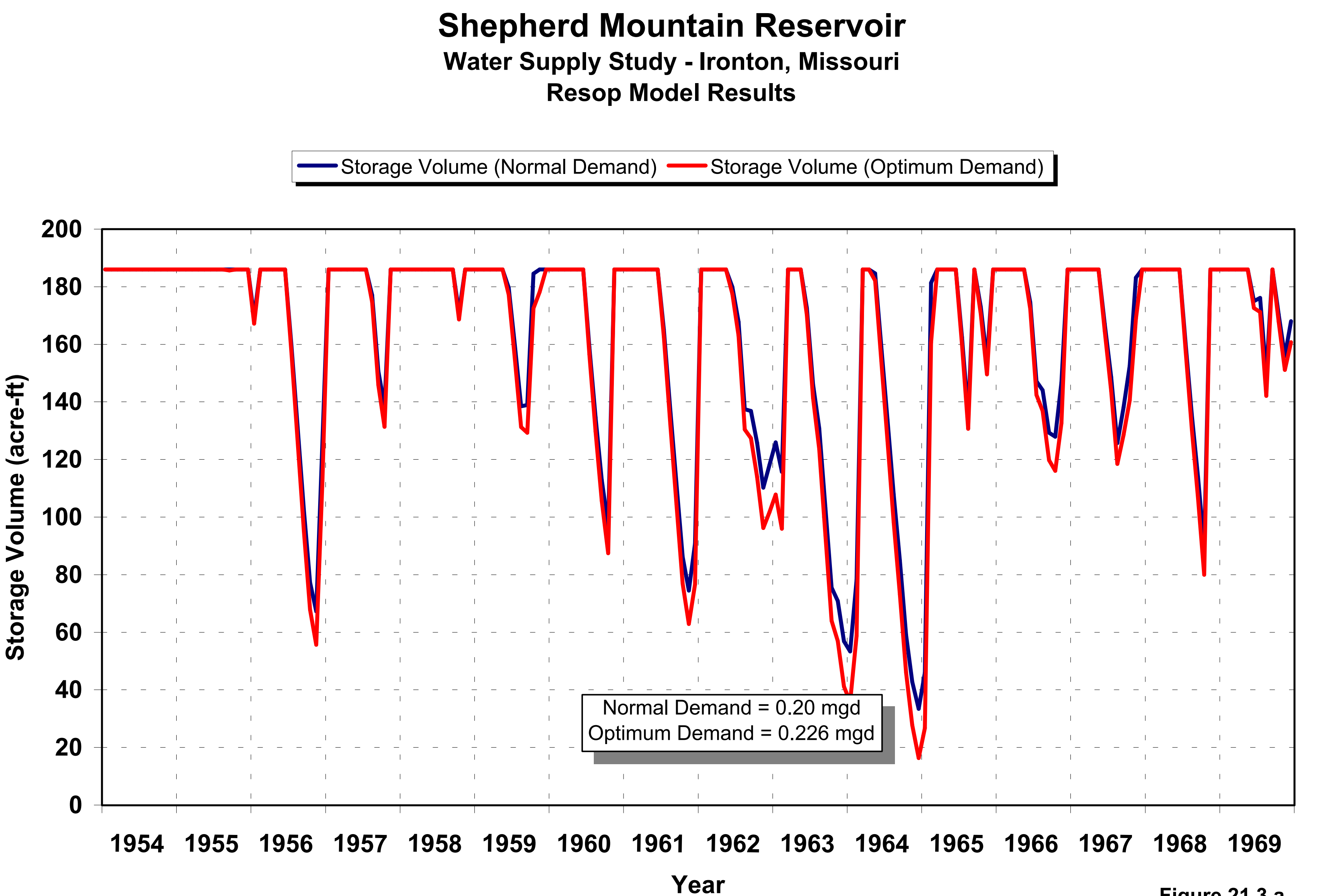

Shepherd Mountain Reservoir
Water Supply Study - Ironton, Missouri
Resop Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Storage Volume (acre-ft)
200
180
160
140
120
100
80
60
40
20
0
Normal Demand = 0.20 mgd
Optimum Demand = 0.226 mgd
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
Year

Figure 21.3.a

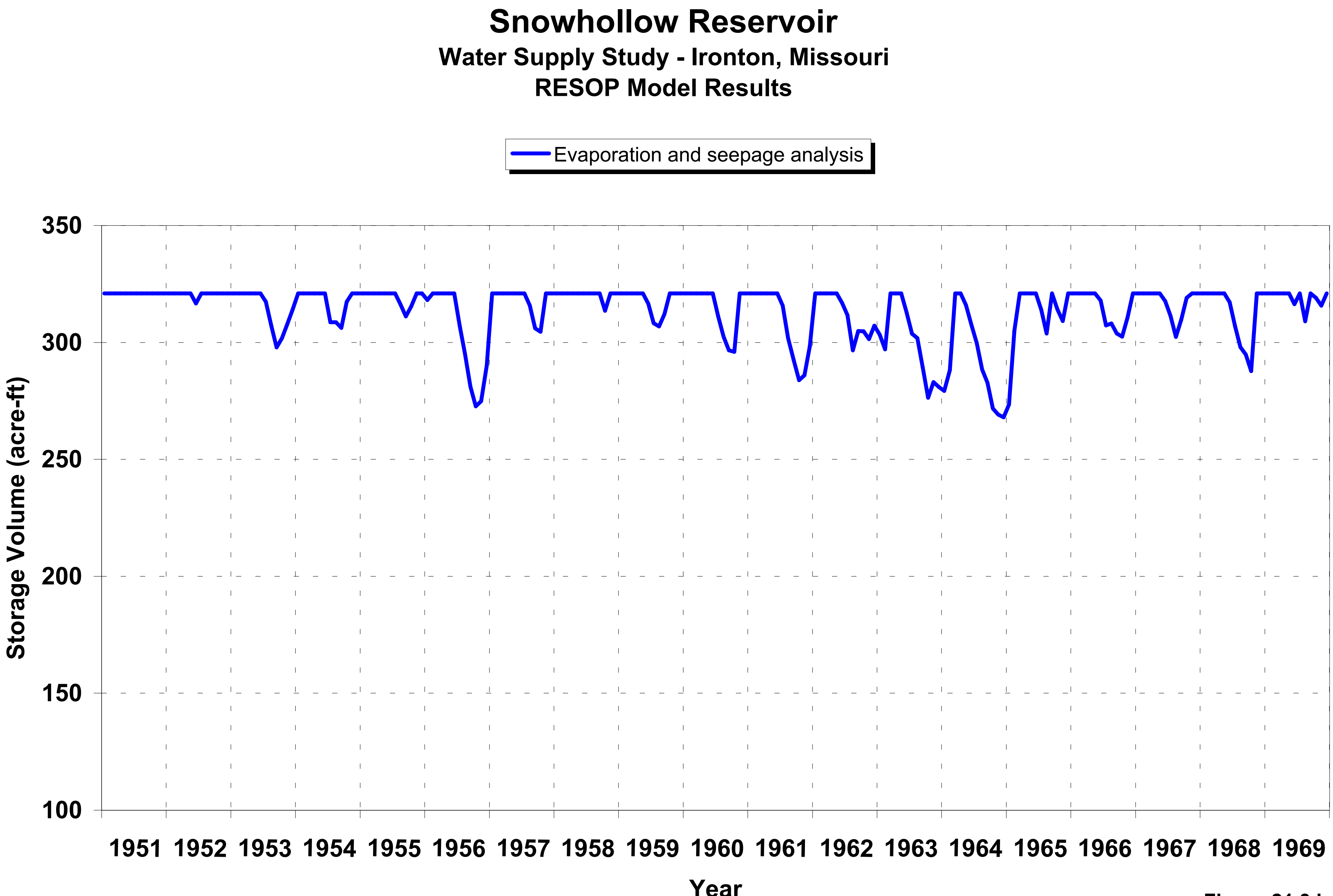

Snowhollow Reservoir
Water Supply Study - Ironton, Missouri
RESOP Model Results
Evaporation and seepage analysis
Storage Volume (acre-ft)
350
300
250
200
150
100
1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
Year

Figure 21.3.b

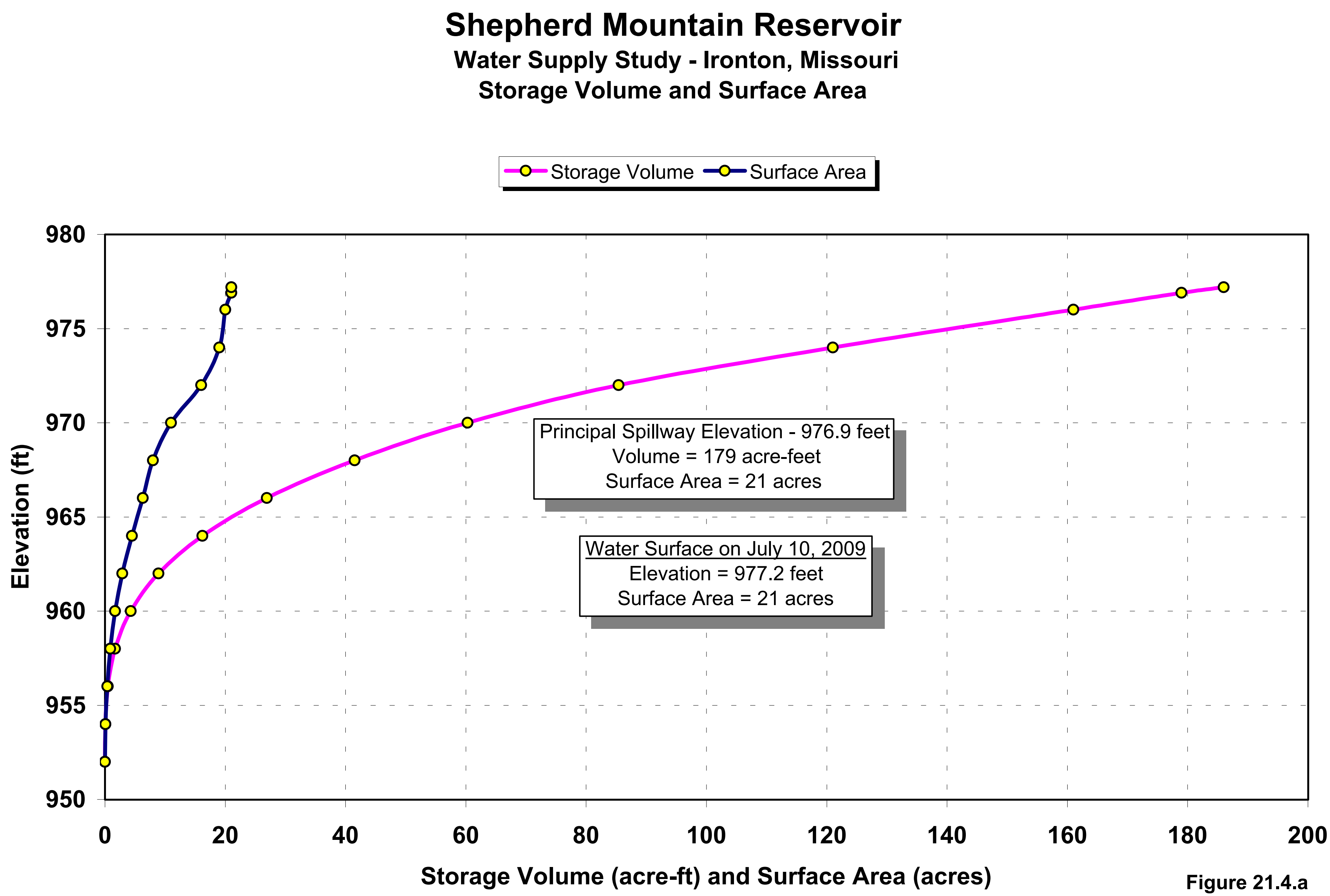

Shepherd Mountain Reservoir
Water Supply Study - Ironton, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Principal Spillway Elevation - 976.9 feet
Volume = 179 acre-feet
Surface Area = 21 acres
Water Surface on July 10, 2009
Elevation = 977.2 feet
Surface Area = 21 acres
Elevation (ft)
980
975
970
965
960
955
950
0
20
40
60
80
100
120
140
160
180
200
Storage Volume (acre-ft) and Surface Area (acres)

Figure 21.4.a

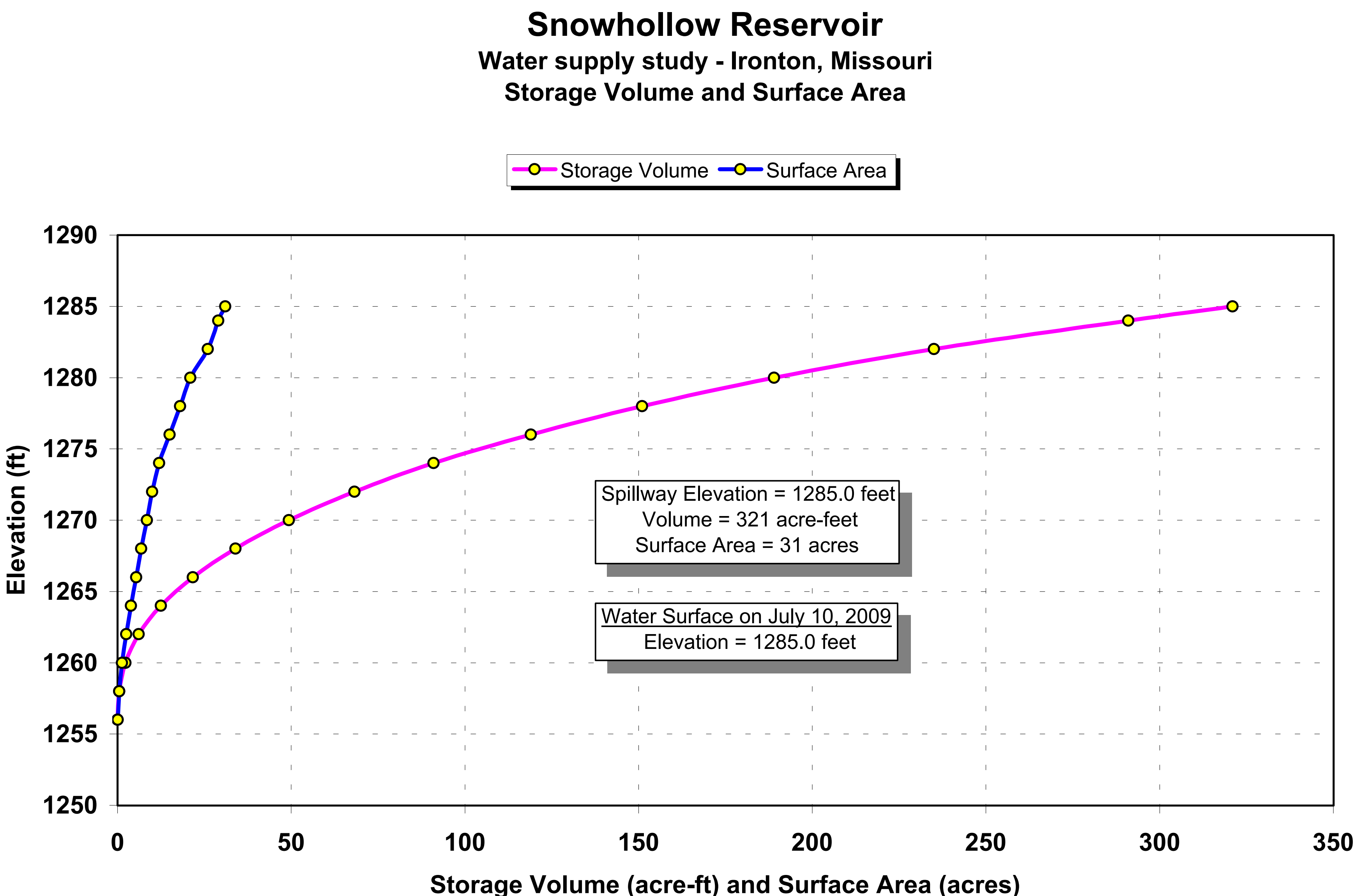

Snowhollow Reservoir
Water supply study - Ironton, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
1290
1285
1280
1275
1270
1265
1260
1255
1250
Elevation (ft)
Spillway Elevation = 1285.0 feet
Volume = 321 acre-feet
Surface Area = 31 acres
Water Surface on July 10, 2009
Elevation = 1285.0 feet
0
50
100
150
200
250
300
350
Storage Volume (acre-ft) and Surface Area (acres)

Figure 21.4.b

Jamesport Reservoir
Water Supply Study – Jamesport, Missouri
Drought Assessment Analysis

I. Overview

Jamesport Reservoir (figure 22.1) is located in east central Daviess County, Missouri. The Jamesport Lake is located approximately two miles north of Jamesport, north of highway 6. Jamesport Reservoir supplies Jamesport with water to meet their demand. The Jamesport Reservoir serves a population of approximately 600 with an estimated water demand of 65,000 gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). Drainage area of the lake is 900 acres. Jamesport Lake was critically low in 1988 and since then, the lake was enlarged to provide additional storage.

Jamesport is not considered a major water user. As a result they have not been reporting their historical water use to Missouri Department of Natural Resources. The Safe Drinking Water Information System (SDWIS) database indicates they are currently using an average of 60,000 gallons per day.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Jamesport Reservoir. The model assumes that ‘Normal’ demand for Jamesport is 60,000 gallons per day and that ‘Optimum’ yield from the lake is 69,050 gallons per day. Figure 22.3 illustrates these relationships.

II. Drought Assessment Summary

The Jamesport Reservoir meets Jamesport’s water demand of 60,000 gallons per day. In 1956 the lake would have had 33 acre-feet remaining in the reservoir. The demand on the reservoir was approximately 60,000 gallons per day, and when this demand value is applied to the reservoir during the drought of record in the 1950’s, water remaining in the reservoir would be alarmingly low.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of James Port Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on July 16, 2000. Surface area of the lake and associated storage volume capacities are illustrated in figure 22.4.

Jamesport Lake Physical Data

Jamesport City Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
869.0	0.01	0.001	
871.0	0.43	0.35	
873.0	1.47	2.14	
875.0	2.78	6.39	
877.0	4.39	13.54	
879.0	6.25	24.07	
881.0	9.62	39.38	
883.0	12.44	61.53	
885.0	15.02	89.26	
887.0	17.04	121.15	
889.0	19.49	157.52	Lake Conditions on July 16, 2000
889.3	20.14	163.46	Spillway

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[LIMITS]

Maximum storage……………………………………………………………163.5 acre-feet
Minimum Pool storage…………………………………………………………..10 acre-feet
Drainage basin size………………………………………………………….1.41 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[SEEPAGE]

Seepage from Jamesport Reservoir is approximately 2.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation values for the drought of record were obtained from the Gallatin, Missouri gauge.

Average precipitation in Gallatin was 36.6 inches between 1951 and 2001. Precipitation values for the drought of record were obtained from Gallatin, Missouri (approximately 3 miles west of Gallatin). The most severe drought occurred between 1953 and 1957 with annual precipitation values in Gallatin of 20.07 inches, 33.55 inches, 28.27 inches, 27.88 inches, and 42.38 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Weldon River stream gauge at Mill Grove Missouri (a tributary of the Grand River), located approximately 27 miles northeast of Jamesport. These values were compared to the runoff at the East Fork Big Creek located at Bethany. When this regional runoff value is inconsistent with precipitation values recorded for Jamesport, individual storm events were considered. Antecedent

rainfall was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Jamesport Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

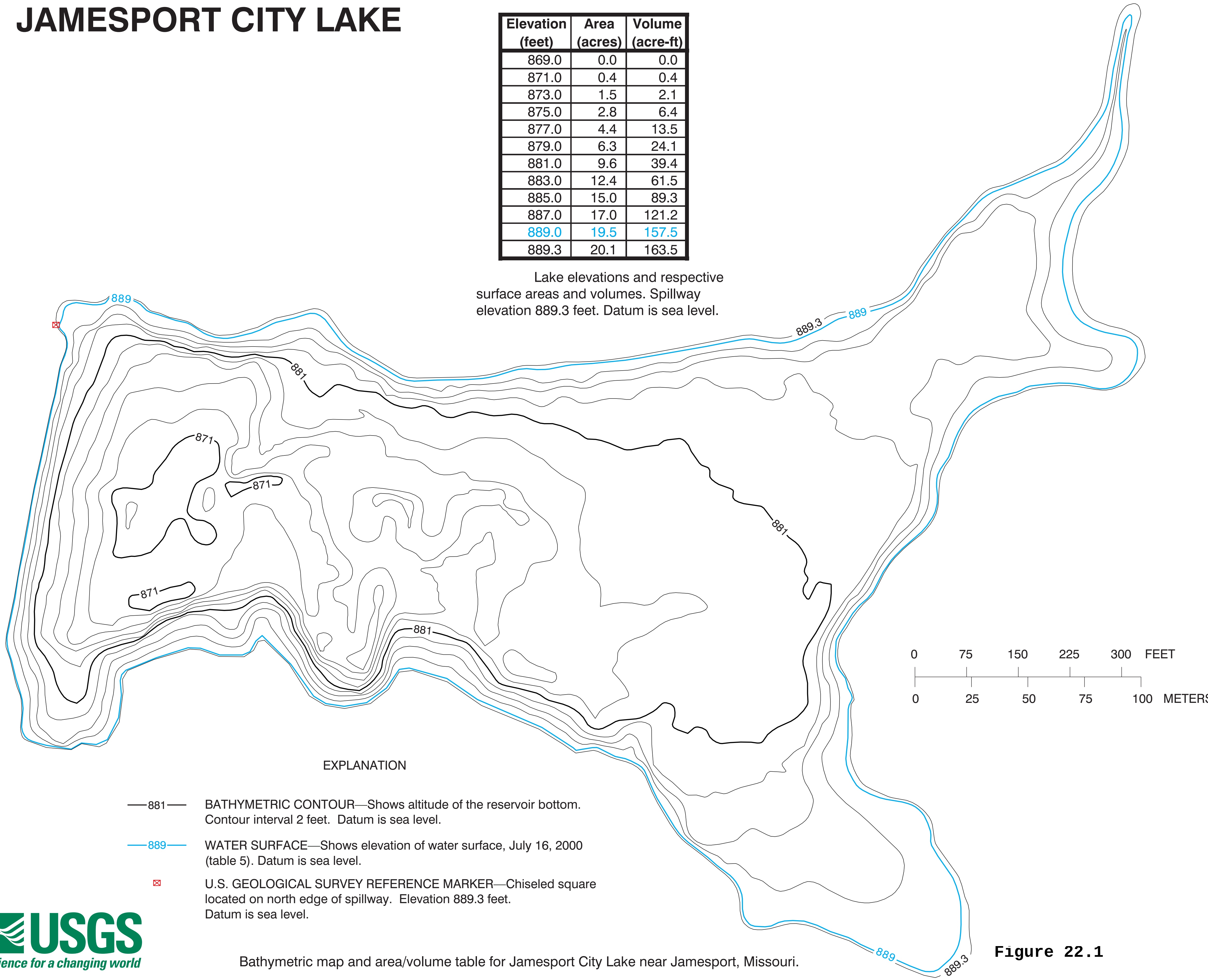
[DEMAND]

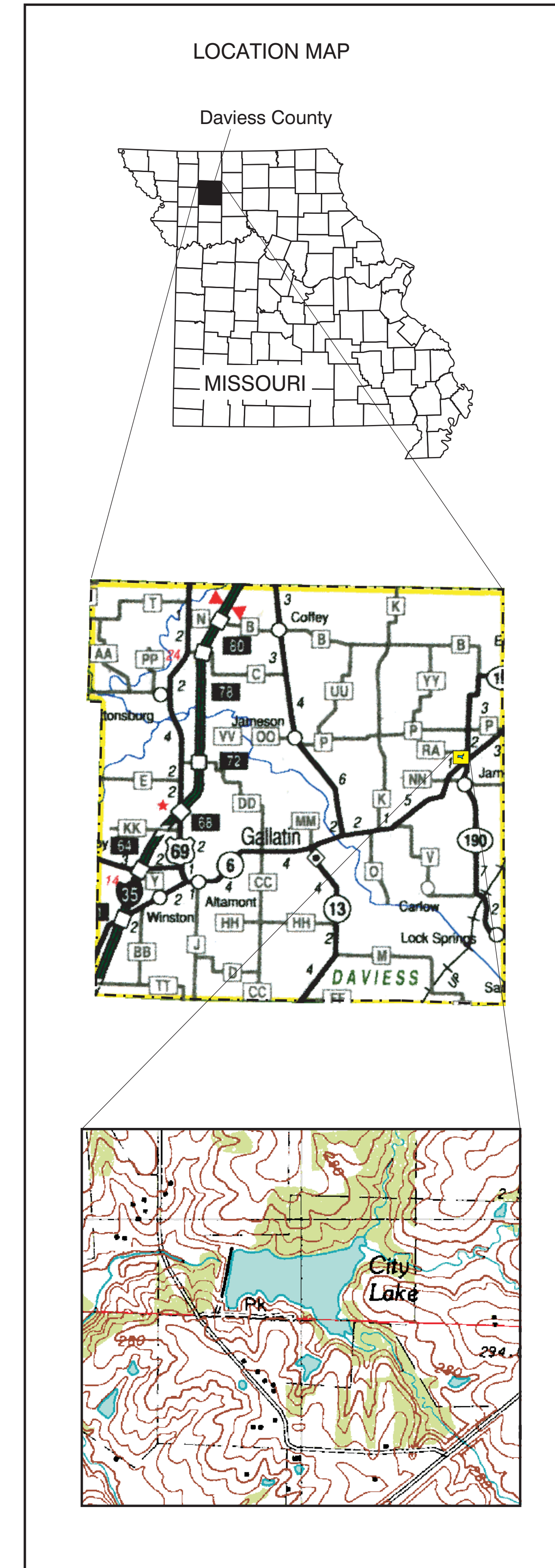
The demand used for Jamesport's analysis came from Missouri safe drinking water information system (SDWIS). They reported Jamesport is 60,000 gallons per day, which was used for this analysis.

JAMESPORT CITY LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
869.0	0.0	0.0
871.0	0.4	0.4
873.0	1.5	2.1
875.0	2.8	6.4
877.0	4.4	13.5
879.0	6.3	24.1
881.0	9.6	39.4
883.0	12.4	61.5
885.0	15.0	89.3
887.0	17.0	121.2
889.0	19.5	157.5
889.3	20.1	163.5

Lake elevations and respective surface areas and volumes. Spillway elevation 889.3 feet. Datum is sea level.





EXPLANATION

—881— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—889— WATER SURFACE—Shows elevation of water surface, July 16, 2000 (table 5). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on north edge of spillway. Elevation 889.3 feet. Datum is sea level.

USGS
science for a changing world

Bathymetric map and area/volume table for Jamesport City Lake near Jamesport, Missouri.

Figure 22.1

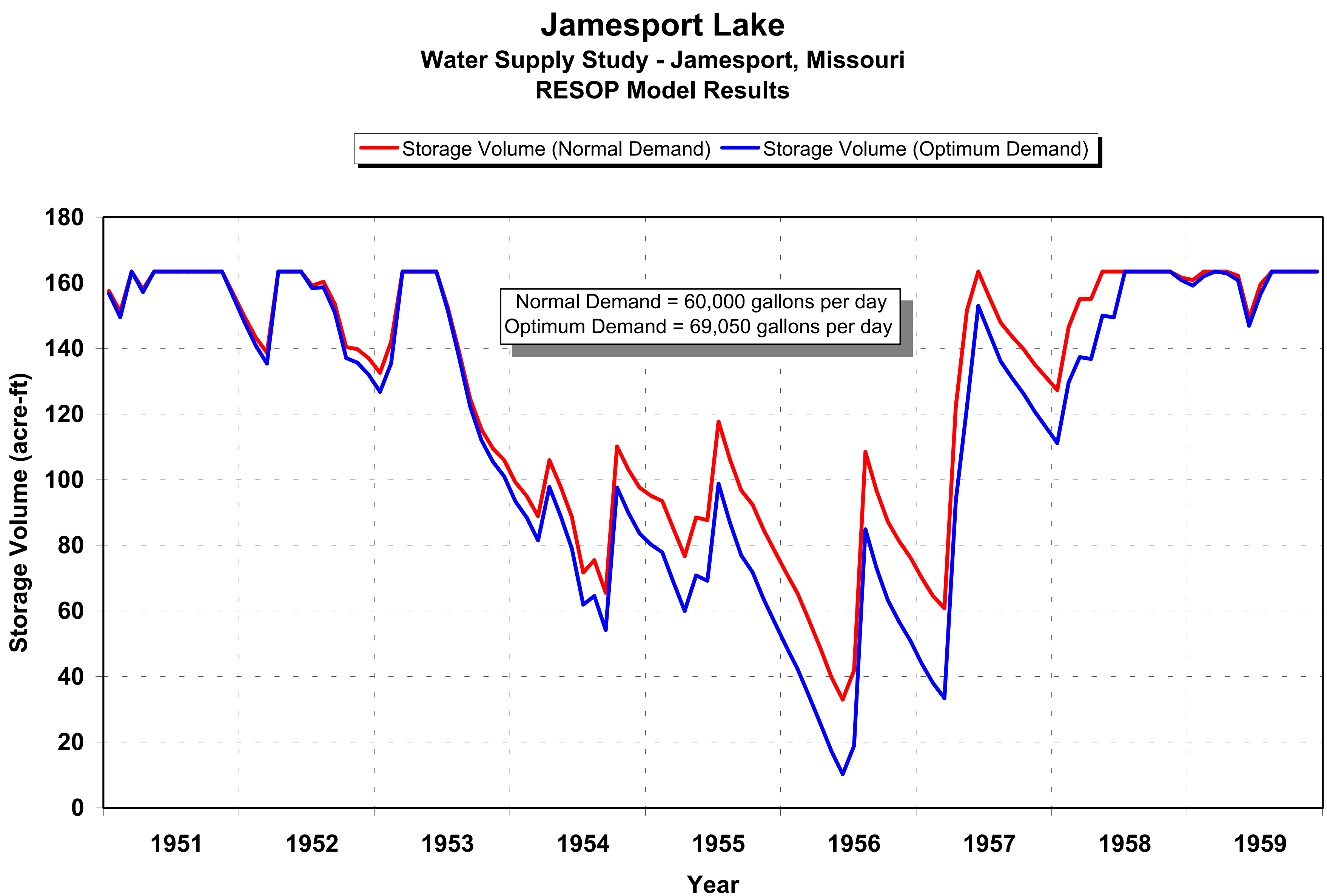

Jamesport Lake
Water Supply Study - Jamesport, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 60,000 gallons per day
Optimum Demand = 69,050 gallons per day
Storage Volume (acre-ft)
0
20
40
60
80
100
120
140
160
180
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 22.3

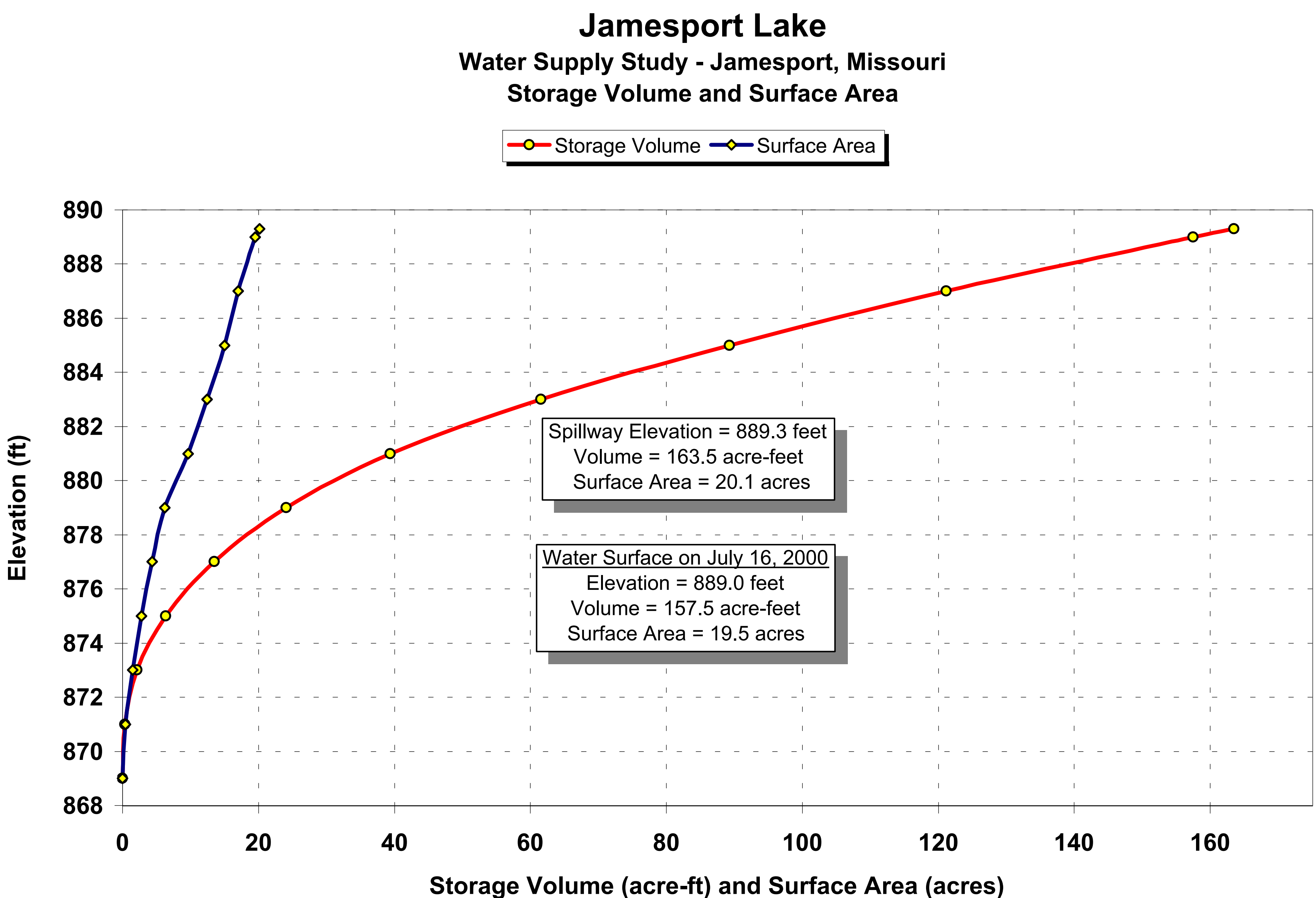

Jamesport Lake
Water Supply Study - Jamesport, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 889.3 feet
Volume = 163.5 acre-feet
Surface Area = 20.1 acres
Water Surface on July 16, 2000
Elevation = 889.0 feet
Volume = 157.5 acre-feet
Surface Area = 19.5 acres
Elevation (ft)
890
888
886
884
882
880
878
876
874
872
870
868
0
20
40
60
80
100
120
140
160
Storage Volume (acre-ft) and Surface Area (acres)

Figure 22.4

King City Reservoirs
Water Supply Study – King City, Missouri
(South Lake and three North Lakes)
Drought Assessment Analysis

King City is located in Southwest Gentry County on Highway 169, South of Stanberry. The King City water supply system is made up of a system of four lakes. The South Lake was constructed following the drought of the late 1980's and is located two miles Southeast of King City (figure 23.1). There are three North Lakes, which make up the original water supply lakes and are about one mile Northeast of King City. These lakes are in series. In addition to the four lakes system two small ponds were constructed to control sediment. One of these is upstream of the Lower North Lake and the other is upstream of the Upper North Lake.

The City of King City draws water directly from the reservoirs to the treatment facility. The King City Reservoir system serves a population of approximately 1,187 with an estimated water demand of 0.110 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

Historical demand on the reservoir has been nearly steady between 1988 through 2001. The highest average daily demand was reported to be 125,000 gallons per day in 1994. Figure 23.2 illustrates historical water demand on the King City Reservoir system.

The drainage area of the South Lake is 0.86 square miles. Drainage areas for the 3 north lakes are Upper North Lake having 0.09 square miles, Middle North Lake 0.375 square miles and Lower North Lake is 0.334 square miles. Total drainage area for the North Lakes system is 0.799 square miles. During large rainfall events discharge through Upper North Lake's spillway was added to the inflow to Middle North Lake's inflow and then discharge through its spillway is added to Lower North Lake's inflow.

To determine the demand required from each reservoir, the optimum demand from each reservoir in the four-lake system was determined. Proportioning of the reported 125,000 gallons per day usage reported by King City was made by the percent of total optimum demand met by each reservoir.

South Lake would supply an average of 73,500 gallons per day of the optimum demand of 78,000 gallons per day.

Lower North Lake would supply an average of 39,400 gallons per day of the optimum demand of 42,000 gallons per day.

Middle North Lake would supply an average of 7,300 gallons per day of the optimum demand of 7,800 gallons per day.

Upper North Lake would supply an average of 4,875 gallons per day of the optimum demand of 5,255 gallons per day.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for King City's water supply system of reservoirs. The model assumes that 'Normal' demand for King City is 125,000 gallons per day. Optimum yield from

the system of lakes is 133,250 gallons per day. Figures 23.3.a, 23.3.b, 23.3.c and 23.3.d illustrate these relationships.

II. Drought Assessment Summary

The King City system of reservoirs meets their current demand for water during the historical drought of record occurring in the 1950's without an additional source of water. The 1994 demand on the reservoirs was 125,000 gallons per day, and when this demand value is applied to the reservoir system water supply would be dangerously low with no room for expansion. The estimated optimum yield from King City Reservoir system is 133,250 gallons per day. The most critical period occurred 1957 and 1958. After analyzing effects of 125,000 gallons per day on the reservoir system, South Lake would have 36 acre-feet remaining in the lake, Lower North Lake would have 52 acre-feet, Middle North Lake would have 21 acre-feet and Upper North Lake 8 acre-feet.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of King City Lakes were conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on April July 19, 2000. Surface area of the lake and associated storage volume capacities are illustrated in figures 23.4.a, 23.4.b, 23.4.c, and 23.4.d.

South Reservoir				***Lower North Reservoir***		
Elevation (feet)	Area acres)	Volume (acre-feet)		Elevation (feet)	Area (acres)	Volume (acre-feet)
1010	0.02	0.003		1016	0.85	0.17
1012	0.54	0.38		1017	3.82	2.17
1014	2.36	2.97		1018	7.66	8.00
1016	5.15	10.55		1019	9.98	16.92
1018	8.08	23.83		1020	11.93	27.91
1020	11.24	43.23		1021	13.54	40.65
1022	15.05	69.38		1022	14.83	54.86
1024	18.60	103.34		1023	16.04	70.28
1025.4	21.09	131.03		1024	17.17	86.90
1026	22.36	144.06		1025	18.19	104.59
1028	27.02	193.35		1026	19.27	123.33
1030	32.83	252.81		1027	20.61	143.23
1032	39.42	324.85		1028	21.77	164.45
1034	47.66	411.55		1029	22.98	186.83
				1030	23.93	210.30
				1031	24.81	234.67
				1031.7	25.42	252.24
				1032	25.67	259.91
				1033	26.49	285.99
				1034	27.29	312.88
				1034.7	27.84	332.17
Waters Surface Elevation on July 19, 2000 = 1025.4 feet Spillway Elevation = 1034.0 feet				Waters Surface Elevation on July 19, 2000 = 1031.7 feet Spillway Elevation = 1034.7 feet		

Middle North Reservoir				***Upper North Reservoir***		
Elevation (feet)	Area (acres)	Volume (acre-feet)		Elevation (feet)	Area (acres)	Volume (acre-feet)
1026	1.11	0.18		1039	0.26	0.10
1027	3.54	2.39		1040	0.55	0.51
1028	5.68	7.11		1041	0.93	1.25
1029	6.64	13.30		1042	1.26	2.35
1030	7.67	20.44		1043	1.65	3.79
1031	8.43	28.50		1044	2.30	5.74
1032	8.97	37.22		1045	2.91	8.38
1033	6.32	46.36		1046	3.27	11.47
1034	9.67	55.86		1047	3.50	14.87
1034.6	9.88	61.73		1048	3.66	18.45
1035	10.03	65.71		1049	3.83	22.19
				1049.7	3.96	24.92
				1050	4.01	26.12
				1051	4.28	30.25
				1052	4.70	34.72
				1053	5.25	39.68
Waters Surface Elevation on July 19, 2000 = 1034.6 feet Spillway Elevation = 1035.0 feet				Waters Surface Elevation on July 19, 2000 = 1049.7 feet Spillway Elevation = 1053.0 feet		

Sediment Pond 1a Located upstream of Lower North Lake				***Sediment Pond 3a*** Located upstream of Upper North Lake		
Elevation (feet)	Area (acres)	Volume (acre-feet)		Elevation (feet)	Area (acres)	Volume (acre-feet)
1031	0.44	0.30		1034	0.19	0.08
1032	0.86	0.94		1035	0.64	0.36
1032.6	1.33	1.57		1036	0.81	1.08
1033	1.42	2.13				
1034	1.62	3.65				
1034.7	1.77	4.83				
Water Surface Elevation on July 19, 2000 =1032.6 feet Spillway Elevation = 1032.7				Water Surface Elevation on July 19, 2000 = 1035.0 feet Spillway Elevation = 1036.0 feet		

[LIMITS]

South Lake
Maximum storage ....411 acre-feet
Minimum storage ....17 acre-feet
Drainage basin size .... 0.86 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

Lower North Lake
Maximum storage ....332 acre-feet
Minimum storage ....40 acre-feet
Drainage basin size .... 0.334 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

<u>Middle North Lake</u>
Maximum storage ....65 acre-feet
Minimum storage ....20 acre-feet
Drainage basin size .... 0.375 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

<u>Upper North Lake</u>
Maximum storage ....39 acre-feet
Minimum storage ....6 acre-feet
Drainage basin size .... 0.090 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from each of the King City Lakes was estimated to be approximately 1.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoirs are bound by earthen dams composed of compacted clay-rich materials - seepage through the dams are considered negligible.

[RAINFALL]

Average precipitation at Lake Viking was 36.80 inches between 1950 and 2000. Precipitation values for the drought of record were obtained from Gallatin, Missouri (approximately 3 mile west of Lake Viking. The most severe drought occurred between 1953 and 1957 with annual precipitation values in Gallatin of 22.71 inches, 31.70 inches, 27.97 inches, 22.29 inches, and 26.38 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected at the White Cloud Creek gauge near Maryville. When runoff did not appear reasonable compared to rainfall, it was necessary to examine daily rainfall values for that month. Antecedent moisture was estimated for each rainfall event and adjustments to NRCS'S runoff curve number was made to arrive at direct runoff for each storm. (See Appendix A for additional information).

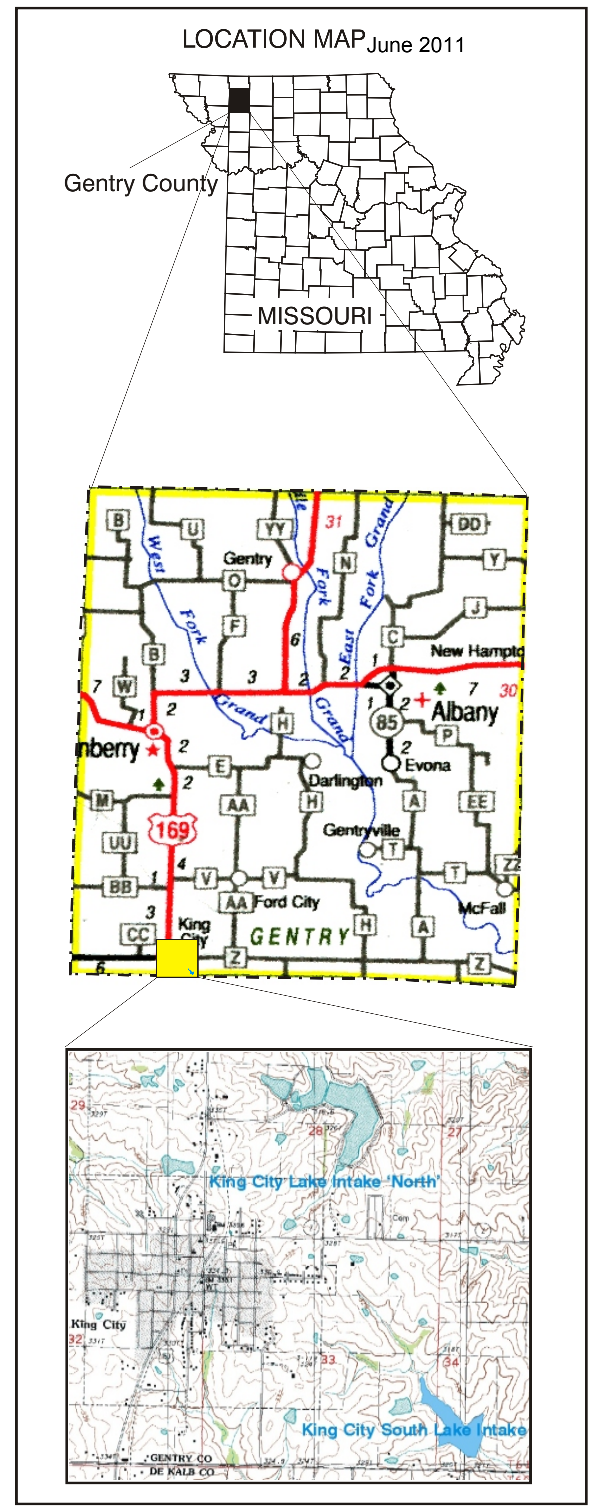
[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from King City Reservoirs due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

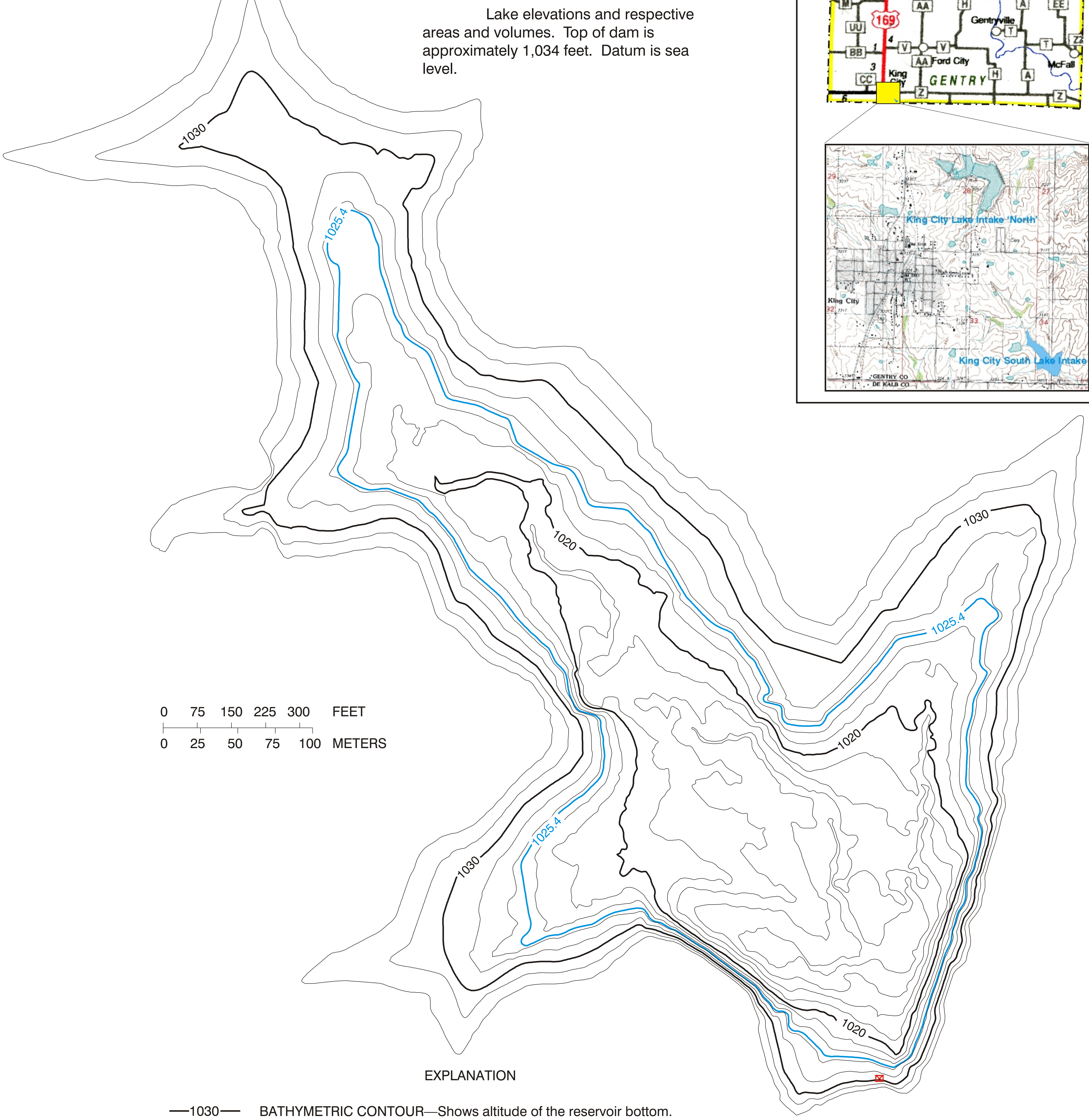
Water demand was obtained from records reported by the city records to Missouri Department of Natural Resources “Major Water Users Data Base”. Their water use has been nearly steady between 1988 and 2001 declining. The largest average daily usage occurred in 1994 with a daily use of 125,000 gallons per day. To determine the volume to be used from each lake, an optimized analysis was made and the same percentages for each lake were used to distribute the 125,000 gallons per day between the four-lake system to obtain current demand.

KING CITY SOUTH LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
1,012.0	0.6	0.4
1,014.0	2.4	3.0
1,016.0	5.2	10.6
1,018.0	8.1	23.9
1,020.0	11.3	43.4
1,022.0	15.1	69.5
1,024.0	18.6	103.5
1,025.4	21.1	131.2
1,026.0	22.4	144.2
1,028.0	26.9	193.4
1,030.0	32.8	252.7
1,032.0	39.4	324.8
1,034.0	47.7	411.5

Lake elevations and respective areas and volumes. Top of dam is approximately 1,034 feet. Datum is sea level.



EXPLANATION

—1030— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—1025.4— WATER SURFACE—Shows elevation of water surface, July 19, 2000 (table 7).Datum is sea level.

U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on east side of boat ramp (unstable surface). Elevation 1029.8 feet. Datum is sea level.

Figure 23.1

Bathymetric map and table of areas/volumes of the King City South Lake near King City, Missouri.

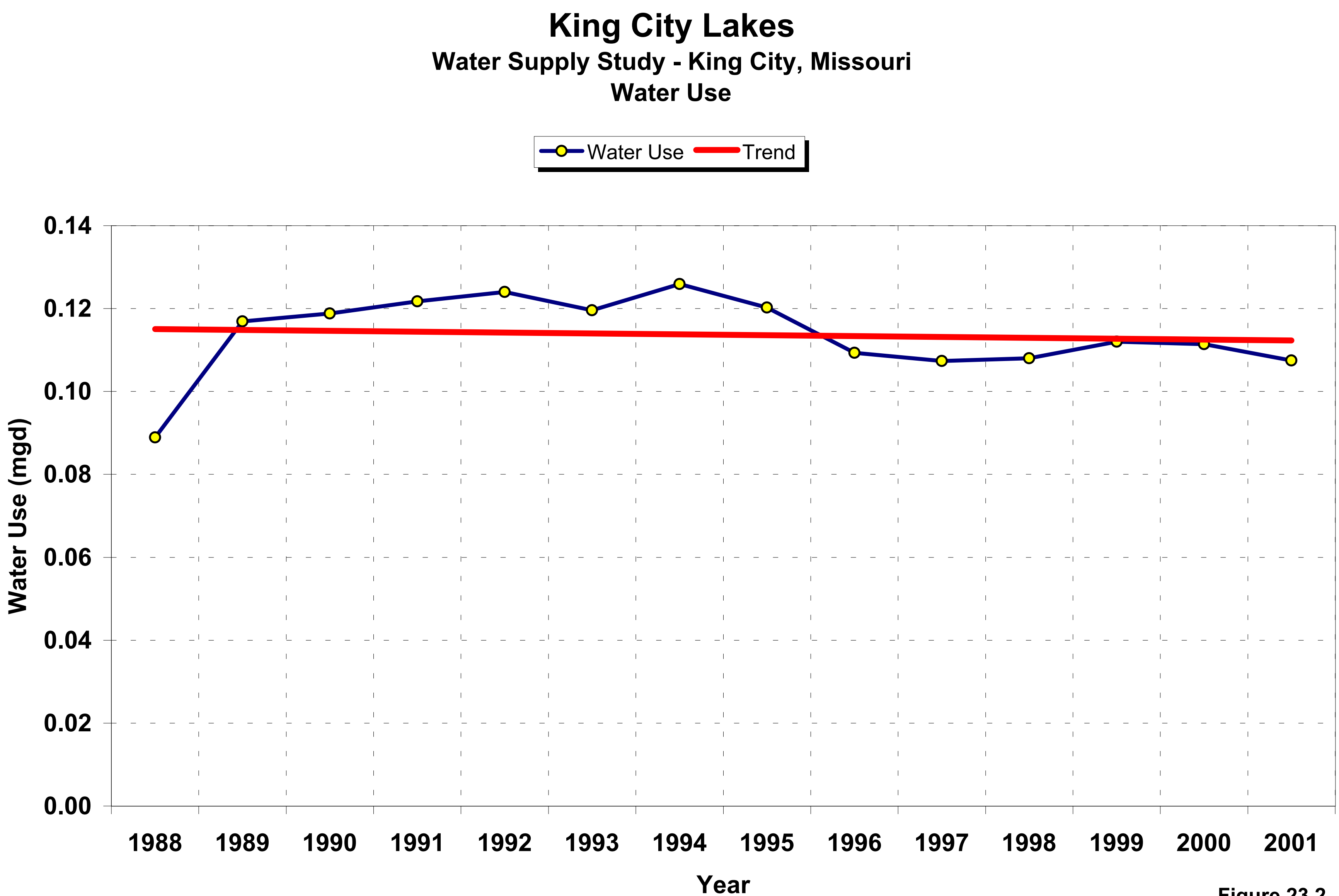

King City Lakes
Water Supply Study - King City, Missouri
Water Use
Water Use
Trend
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Water Use (mgd)
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 23.2

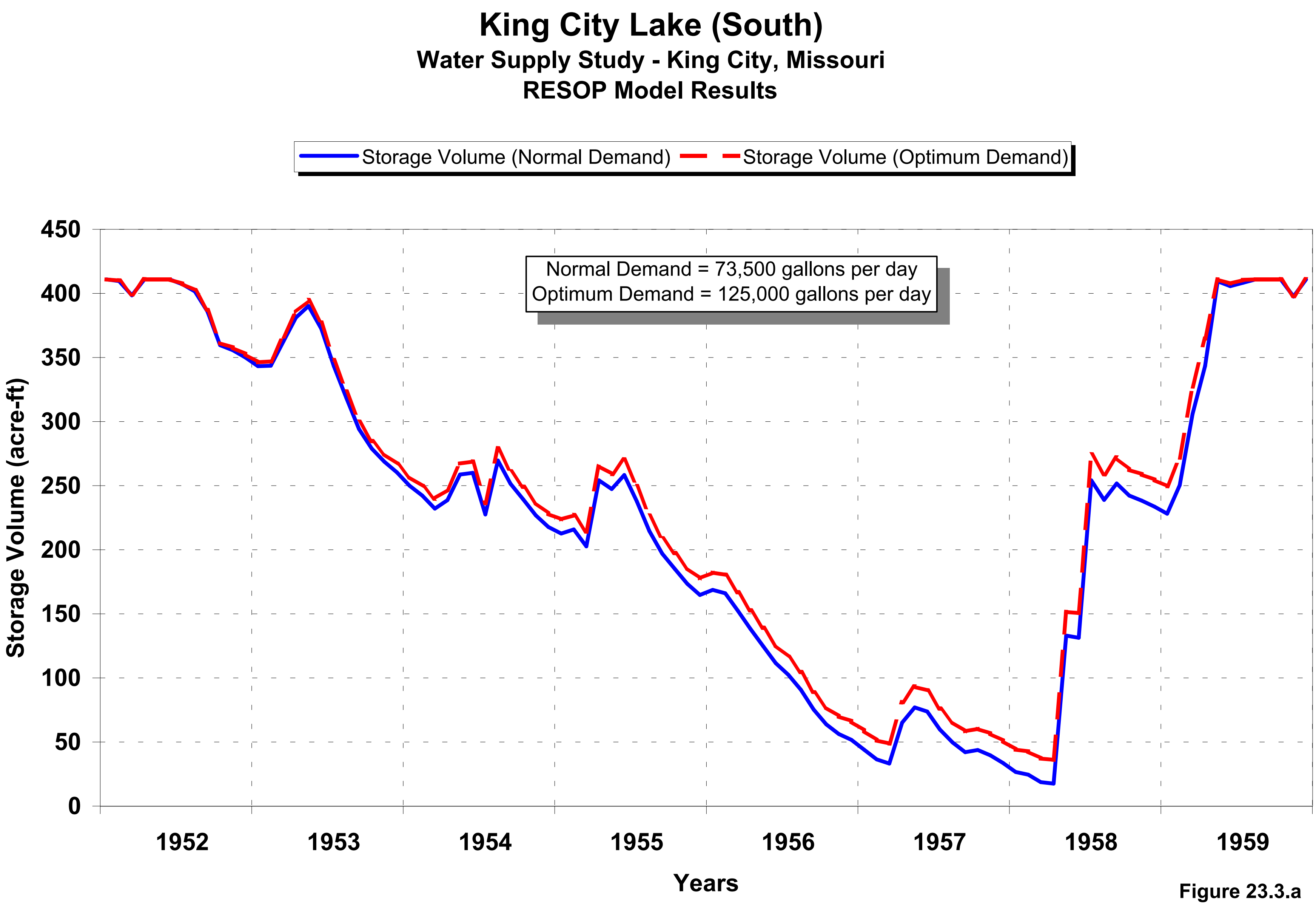

King City Lake (South)
Water Supply Study - King City, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 73,500 gallons per day
Optimum Demand = 125,000 gallons per day
Storage Volume (acre-ft)
450
400
350
300
250
200
150
100
50
0
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 23.3.a

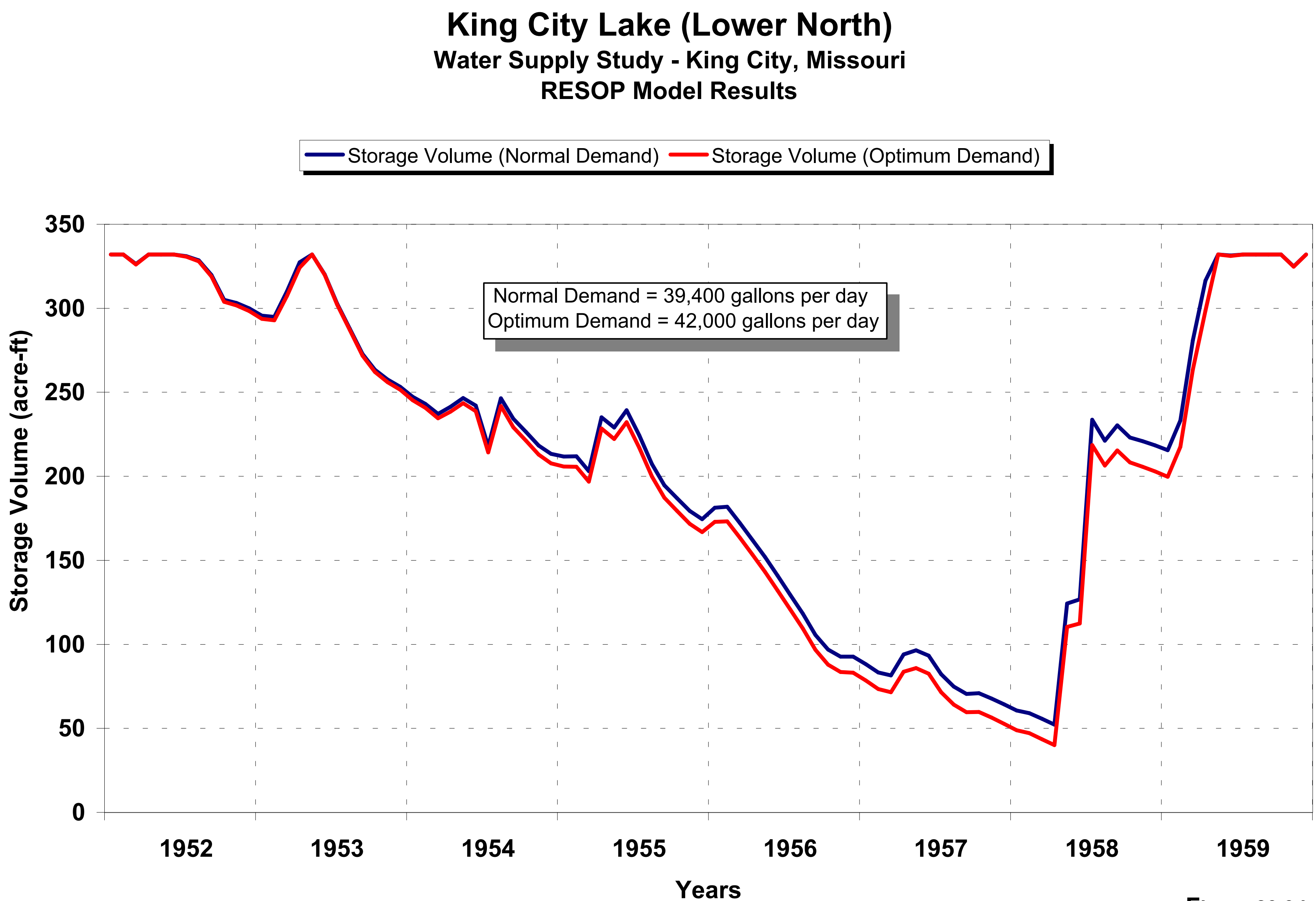

King City Lake (Lower North)
Water Supply Study - King City, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 39,400 gallons per day
Optimum Demand = 42,000 gallons per day
Storage Volume (acre-ft)
350
300
250
200
150
100
50
0
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 23.3.b

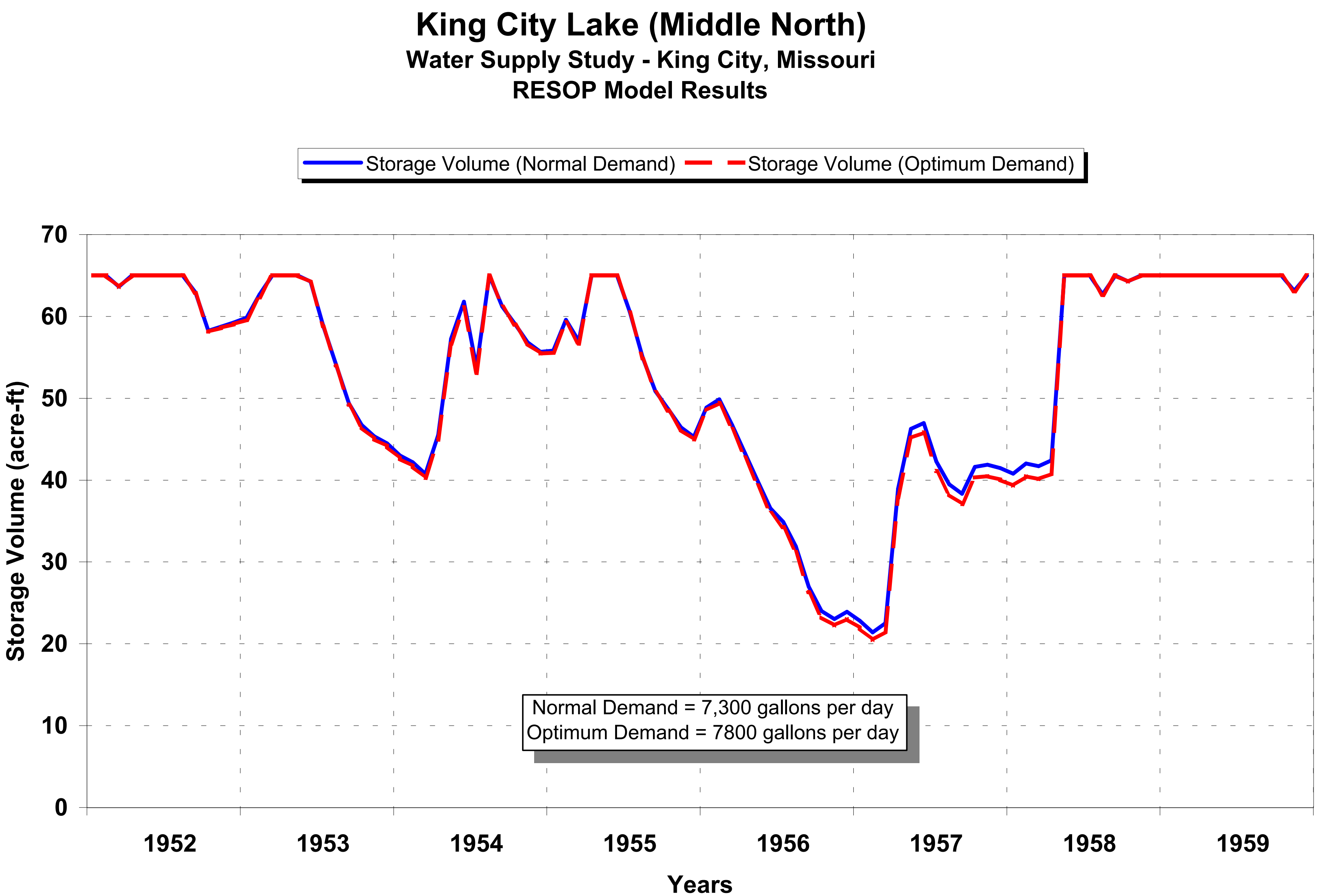

King City Lake (Middle North)
Water Supply Study - King City, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Storage Volume (acre-ft)
70
60
50
40
30
20
10
0
Normal Demand = 7,300 gallons per day
Optimum Demand = 7800 gallons per day
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 22.3.c

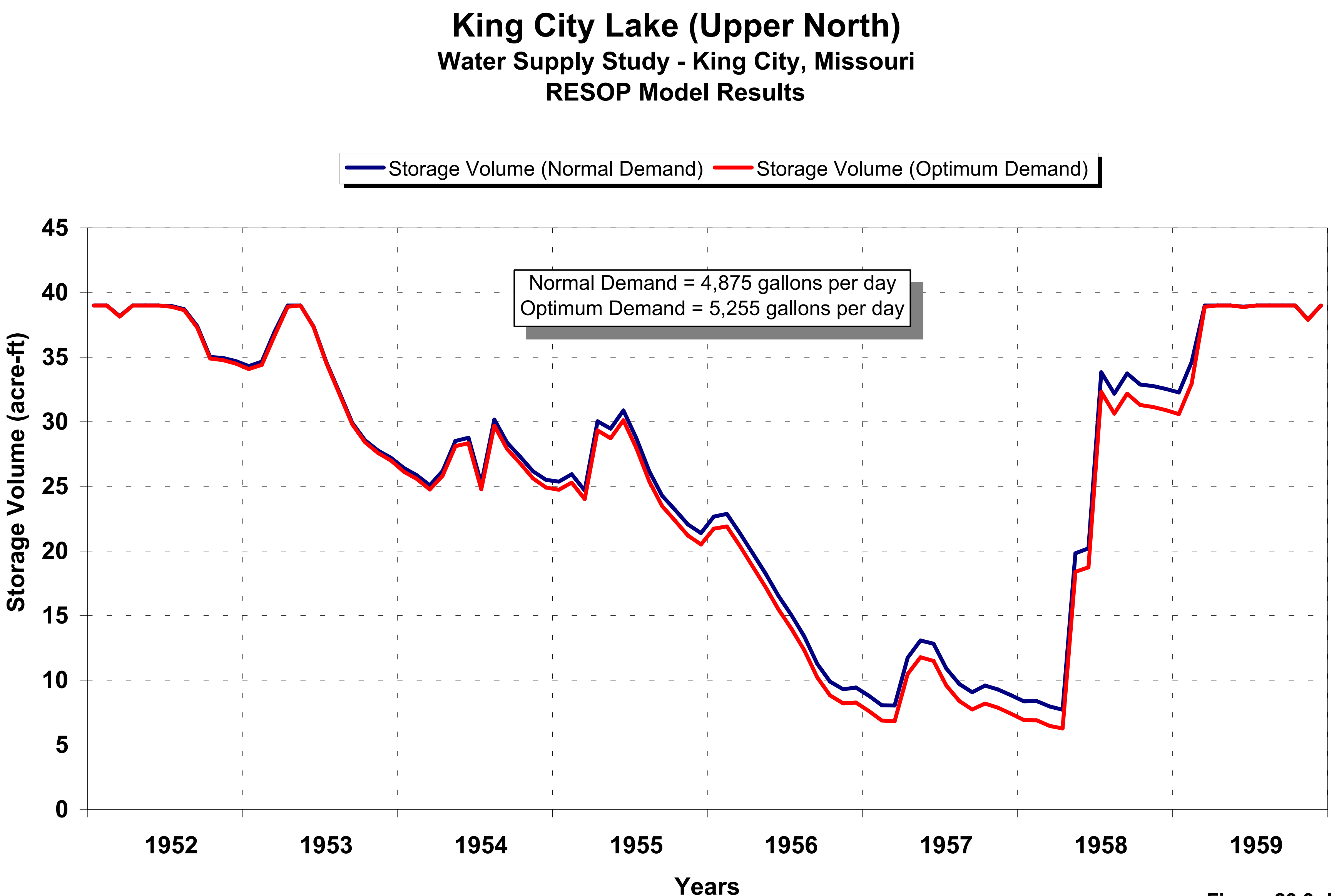

King City Lake (Upper North)
Water Supply Study - King City, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 4,875 gallons per day
Optimum Demand = 5,255 gallons per day
Storage Volume (acre-ft)
45
40
35
30
25
20
15
10
5
0
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 23.3.d

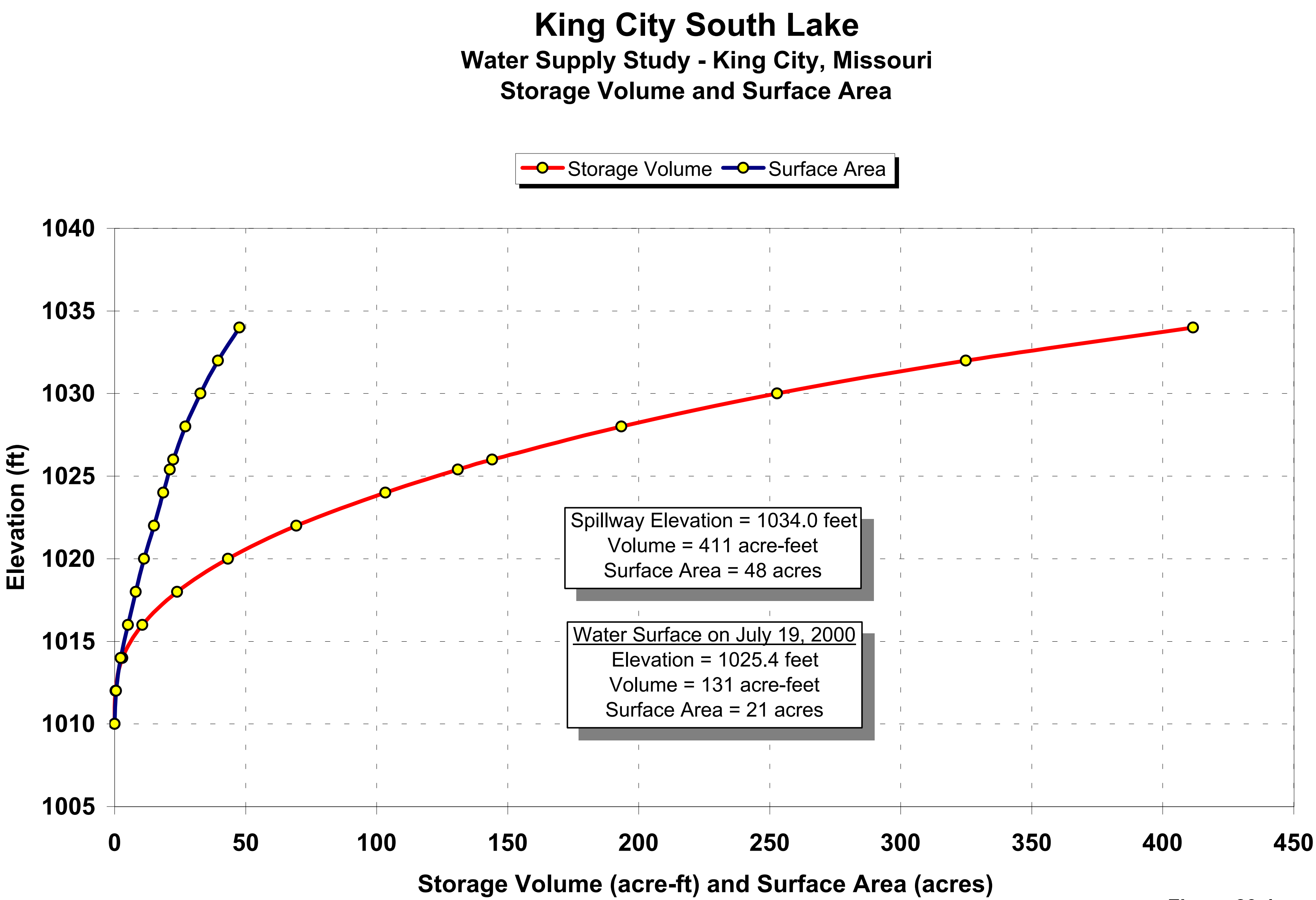

King City South Lake
Water Supply Study - King City, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
1040
1035
1030
1025
1020
1015
1010
1005
Elevation (ft)
Spillway Elevation = 1034.0 feet
Volume = 411 acre-feet
Surface Area = 48 acres
Water Surface on July 19, 2000
Elevation = 1025.4 feet
Volume = 131 acre-feet
Surface Area = 21 acres
0
50
100
150
200
250
300
350
400
450
Storage Volume (acre-ft) and Surface Area (acres)

Figure 23.4.a

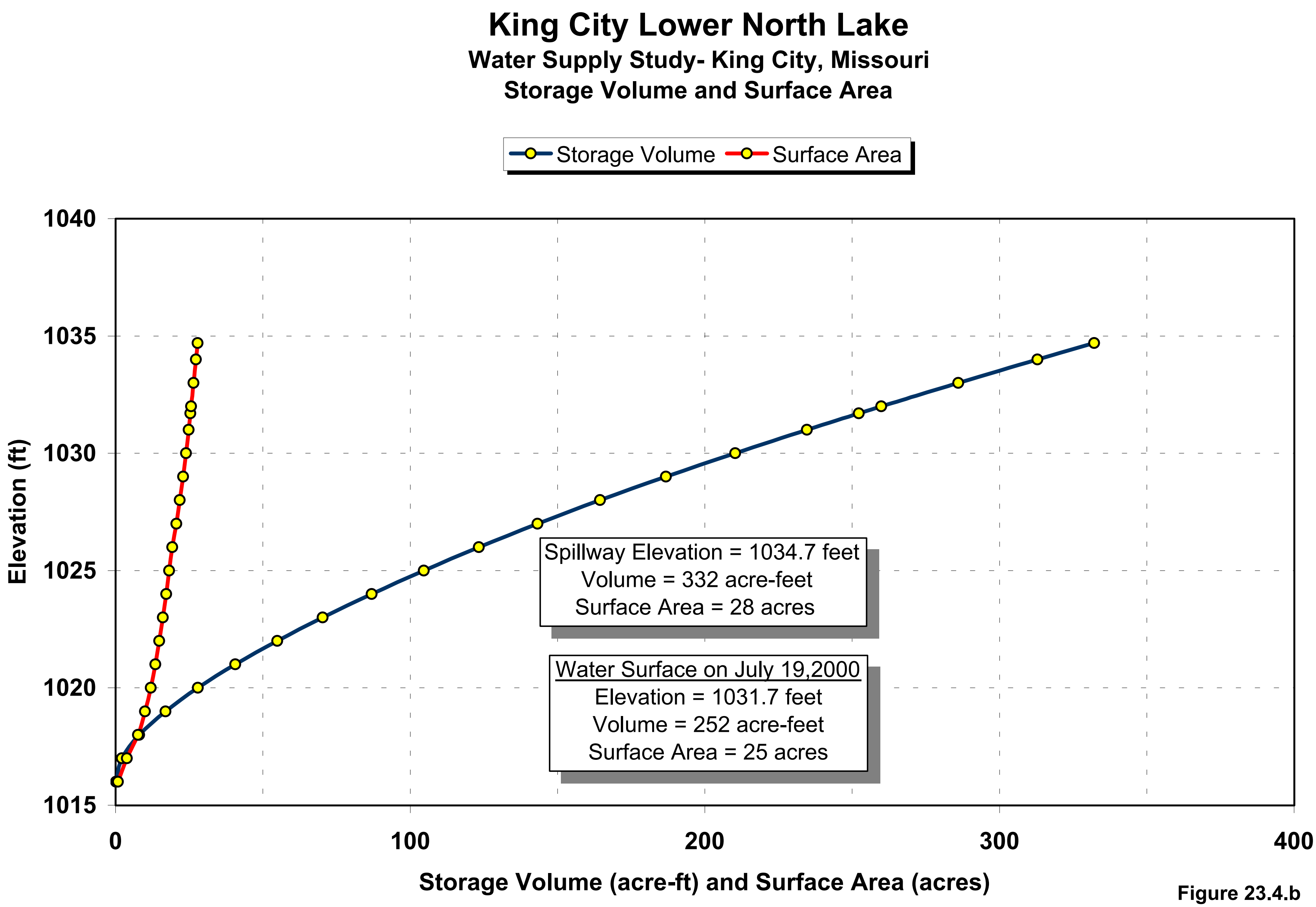

King City Lower North Lake
Water Supply Study- King City, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
1040
1035
1030
1025
1020
1015
Elevation (ft)
0
100
200
300
400
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 1034.7 feet
Volume = 332 acre-feet
Surface Area = 28 acres
Water Surface on July 19,2000
Elevation = 1031.7 feet
Volume = 252 acre-feet
Surface Area = 25 acres

Figure 23.4.b

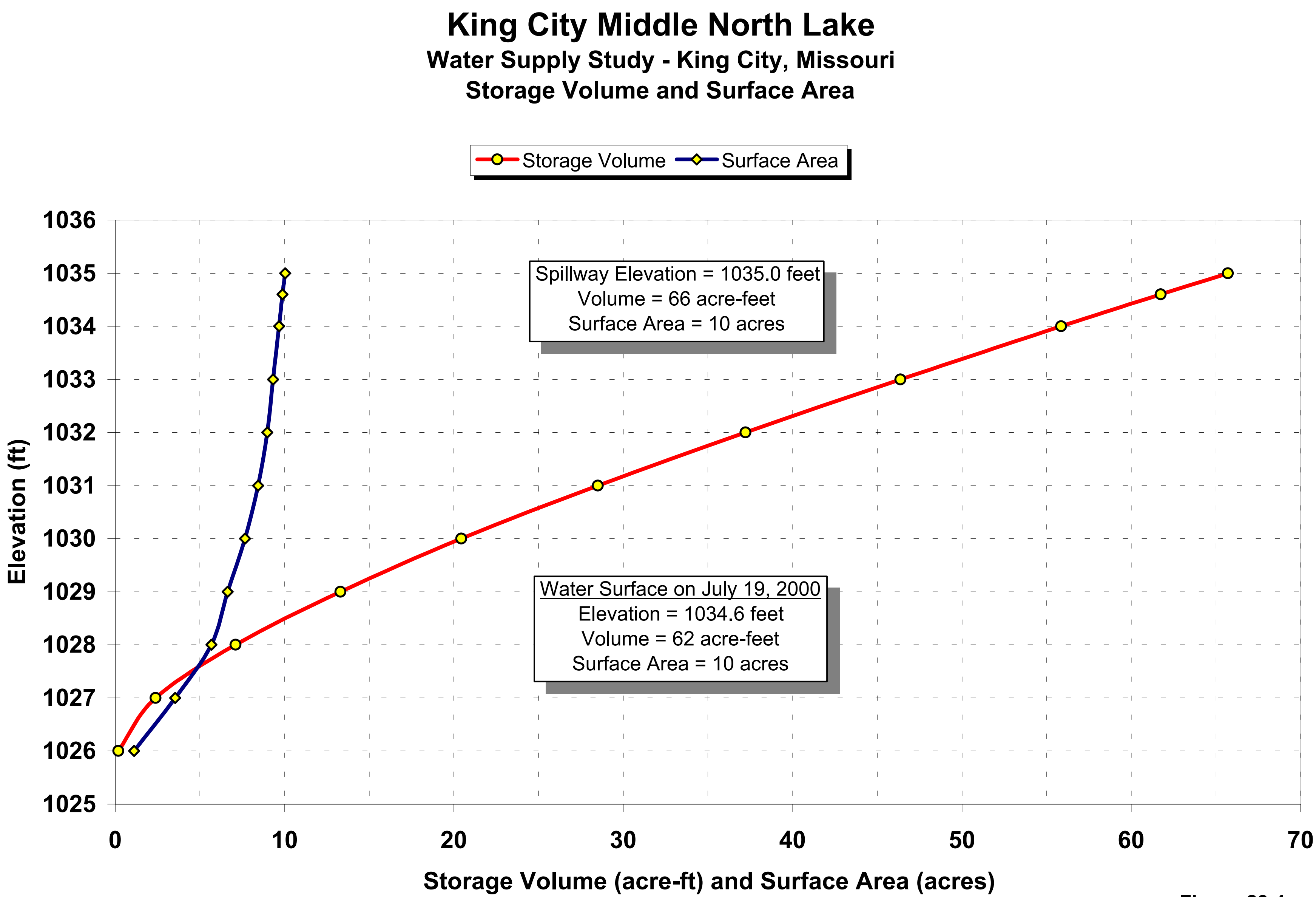

King City Middle North Lake
Water Supply Study - King City, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 1035.0 feet
Volume = 66 acre-feet
Surface Area = 10 acres
Water Surface on July 19, 2000
Elevation = 1034.6 feet
Volume = 62 acre-feet
Surface Area = 10 acres
Elevation (ft)
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
0
10
20
30
40
50
60
70
Storage Volume (acre-ft) and Surface Area (acres)

Figure 23.4.c

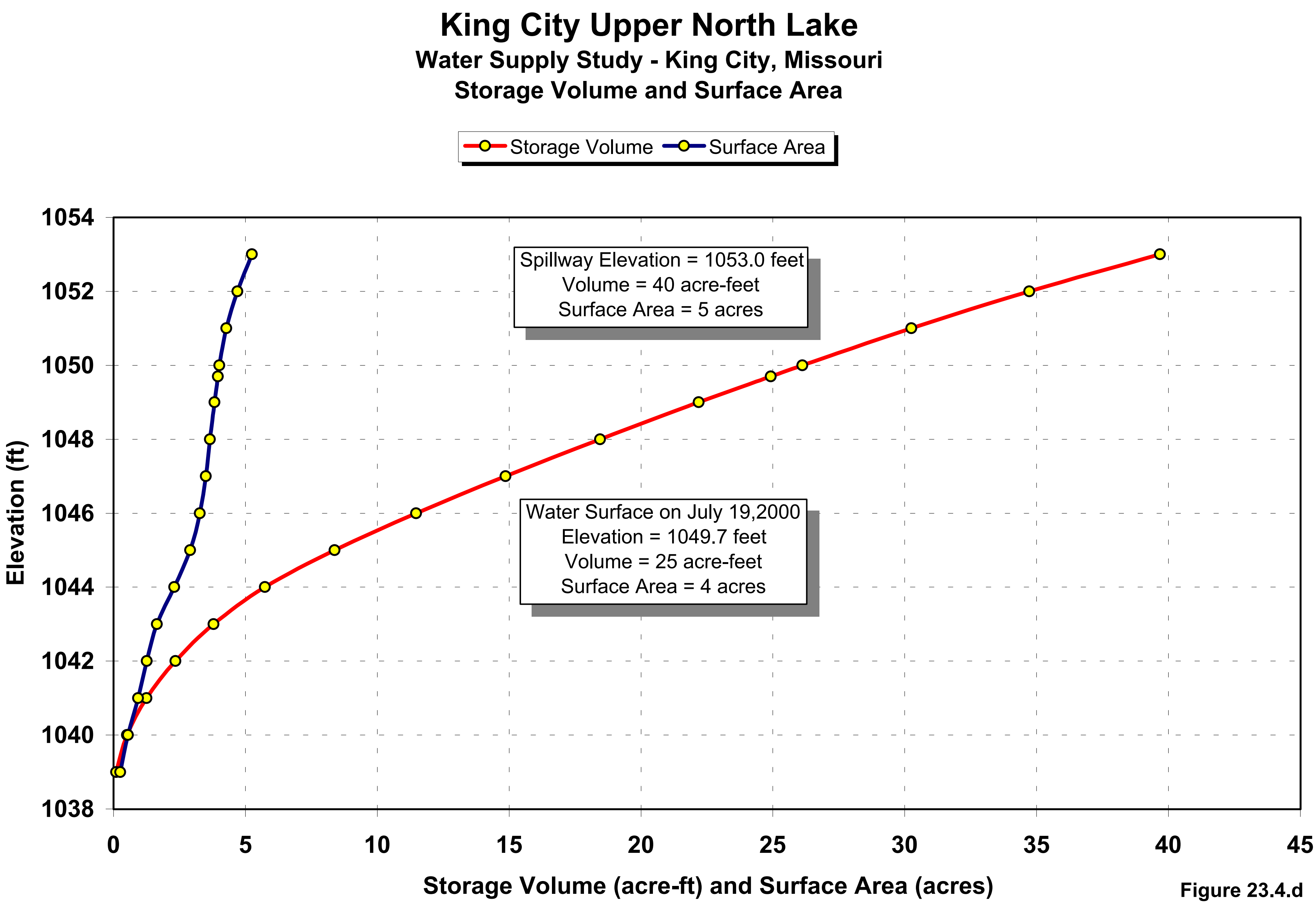

King City Upper North Lake
Water Supply Study - King City, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 1053.0 feet
Volume = 40 acre-feet
Surface Area = 5 acres
Water Surface on July 19,2000
Elevation = 1049.7 feet
Volume = 25 acre-feet
Surface Area = 4 acres
Elevation (ft)
1054
1052
1050
1048
1046
1044
1042
1040
1038
0
5
10
15
20
25
30
35
40
45
Storage Volume (acre-ft) and Surface Area (acres)

Figure 23.4.d

Forest and Hazel Creek Lakes
Water Supply Study – Kirksville, Missouri
Drought Assessment Analysis

I. Overview

Kirksville is in north central Missouri in Adair County. Kirksville's water supply comes from two sources. The largest is Forest Reservoir (figure 24.1.a) located approximately 3.5 miles southwest of the city, and the other is Hazel Creek Reservoir (figure 24.1.b) located approximately 6 miles northwest of the city. The City of Kirksville also sells finished water to Adair County PWSD # 1. The two reservoirs serve a population of approximately 17,000 with an estimated water demand of 2.90 million gallons per day according to the 2008 Census of Missouri Public Water Systems, maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources (Figure 24.2).

Historical demand on the reservoirs in 2000 was reported to be 2.90 million gallons per day. Water demand for this model was 2.90 million gallons per day and was distributed between the two lakes. Water use peaked at 3.74 million gallons per day in 1998 and then returned to expected demand in 1999. Figure 24.2 illustrates historical water demand on both the Forest Reservoir and Hazel Creek Reservoir. The water use trend has been increasing at a rate of 2.06 percent per year.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

To determine fair share demand from the each of the two reservoirs, proportions of the optimum demands from each lake was determined and this ratio contributed its share of the 2.90 million gallons per day. Forest Lake optimized demand is 3.53 million gallons per day (71%) and Hazel Creek Lake is 1.95 million gallons per day (29%). This approach shows Forest Lake would supply 2.06 million gallons per day and Hazel Creek Lake would supply 0.84 million gallons per day.

RESOP model analysis of Forest Lake and Hazel Creek Lake consisted of analyzing the total demand of 2.90 million gallons per day from each reservoir. The proportioned share assigned to each reservoir was evaluated as the normal demand from each reservoir. Forest Reservoir and Hazel Creek Reservoir would contribute 2.06 and 0.84 million gallons per day respectively. Optimum yield from each reservoir was then computed. Figures 24.3.a and 24.3.b demonstrate these results.

II. Drought Assessment Summary

The RESOP analysis of Forest and Hazel Creek Reservoirs demonstrate that Kirksville's demand will be met for the foreseeable future. The 2000 demand on the reservoirs was approximately 2.90 million gallons per day, and when this demand value is applied to the reservoirs during the drought of record in the 1950's, the combination of the two reservoirs would meet Kirksville demand. The estimated optimum yield from Forest Reservoir is 3.53 million gallons per day, and Hazel Creek Reservoir's optimum yield is 1.95 million gallons per day. If the demand of 2.90 million gallons per day were taken from Hazel Creek Reservoir only, the reservoir would be emptied from January 1956 through December 1958. Forest Reservoir would supply the demand of 2.90 million gallons per day without any input from Hazel Creek Reservoir.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Forest Reservoir and Hazel Creek Reservoirs conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on March 2-4, 2005. Surface area of both reservoirs and associated storage volume capacity are illustrated in figure 24.4a and 24.4.b.

Forest Reservoir and Hazel Creek Reservoir Physical Data

Forest Reservoir				Hazel Creek Reservoir		
Elevation (feet)	Area (acres)	Volume (acre-ft)		Elevation (feet)	Area (acres)	Volume (acre-ft)
752	0.5	0.2		800	0.2	0.1
754	2.7	3.0		802	0.9	1.0
756	12.5	15.0		804	4.3	5.0
758	33.4	61.9		806	16.1	23.7
760	57.9	152		808	30.1	71.9
762	81.6	293		810	42.0	143
764	103	476		812	54.6	240
766	126	705		814	69.8	365
768	149	979		816	83.2	518
770	177	1,300		818	97.4	698
772	203	1,680		820	114	909
774	231	2,120		822	134	1,160
776	246	2,600		824	154	1,450
778	274	3,130		826	175	1,770
780	302	3,700		828	197	2,150
782	329	4,330		830	220	2,560
784	358	5,020		832	244	3,030
786	382	5,760		834	270	3,540
788	406	6,550		836	295	4,110
790	430	7,380		838	323	4,720
792	455	8,270		840	356	5,400
794	478	9,200		842	388	6140
796	506	10,200		844	421	6,950
798	537	11,200		846	456	7,830
800	577	12,300		847.8	493	8,680
800.2	583	12,500				
Spillway Elevation = 800.2 feet Water Surface Elevation on March 1-2, 2005 = 800 feet				Spillway Elevation = 847.8 feet Water Surface Elevation on March 2-4, 2005 = 847.2 feet		

[LIMITS]

<u>Forest Reservoir</u>
Maximum storage…………………………………………………….…………….12,500 acre-feet
Minimum storage…………………………………………………...………………490 acre-feet
Drainage basin size…………………………………………….…...………..14.71 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

<u>Hazel Creek Reservoir</u>
Maximum storage………………………………………….……..……………8,780 acre-feet
Minimum storage……………………….………………………..……..………240 acre-feet
Drainage basin size…………………………………………….……..……8.07 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Forest Reservoir and Hazel Creek Reservoir is estimated to be approximately 3.5 inches per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoirs are bound by an earthen dams composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Rainfall data for the evaluation period of January 1951 through December 1959 was obtained from the Kirksville airport rain gauge.

Average annual rainfall at Kirksville is for the period 1951 through 2000 is 34.00 inches. The most severe drought occurred between 1953 and 1957 with annual precipitation values of 24.66, 36.10, 29.45, 26.50, and 43.17 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Middle Fabius stream gauge near Baring, located approximately 8 miles south of Memphis, Missouri. The Middle Fabius watershed rises in northern Adair County and flows eastward to the gauge in Scotland County. When this regional runoff value is inconsistent with precipitation values recorded for Kirksville, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

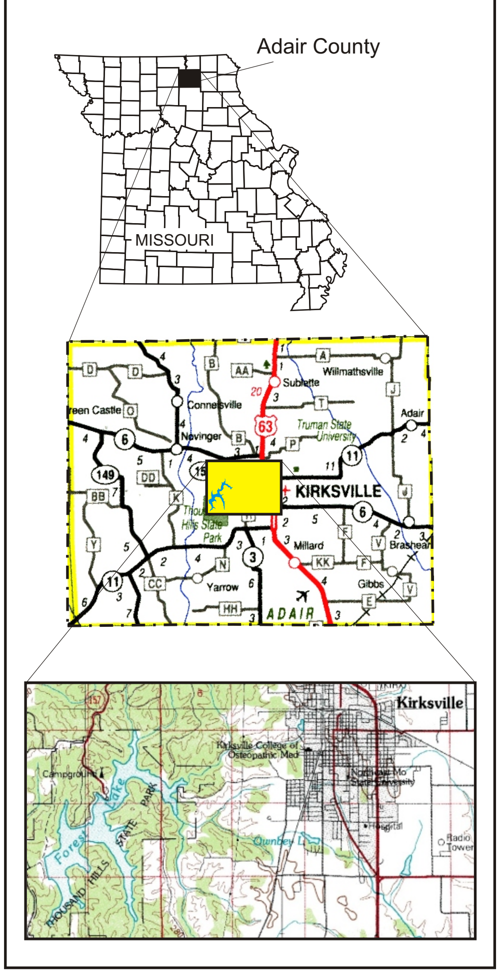
Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Kirksville's Reservoirs due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan evaporation to lake evaporation.

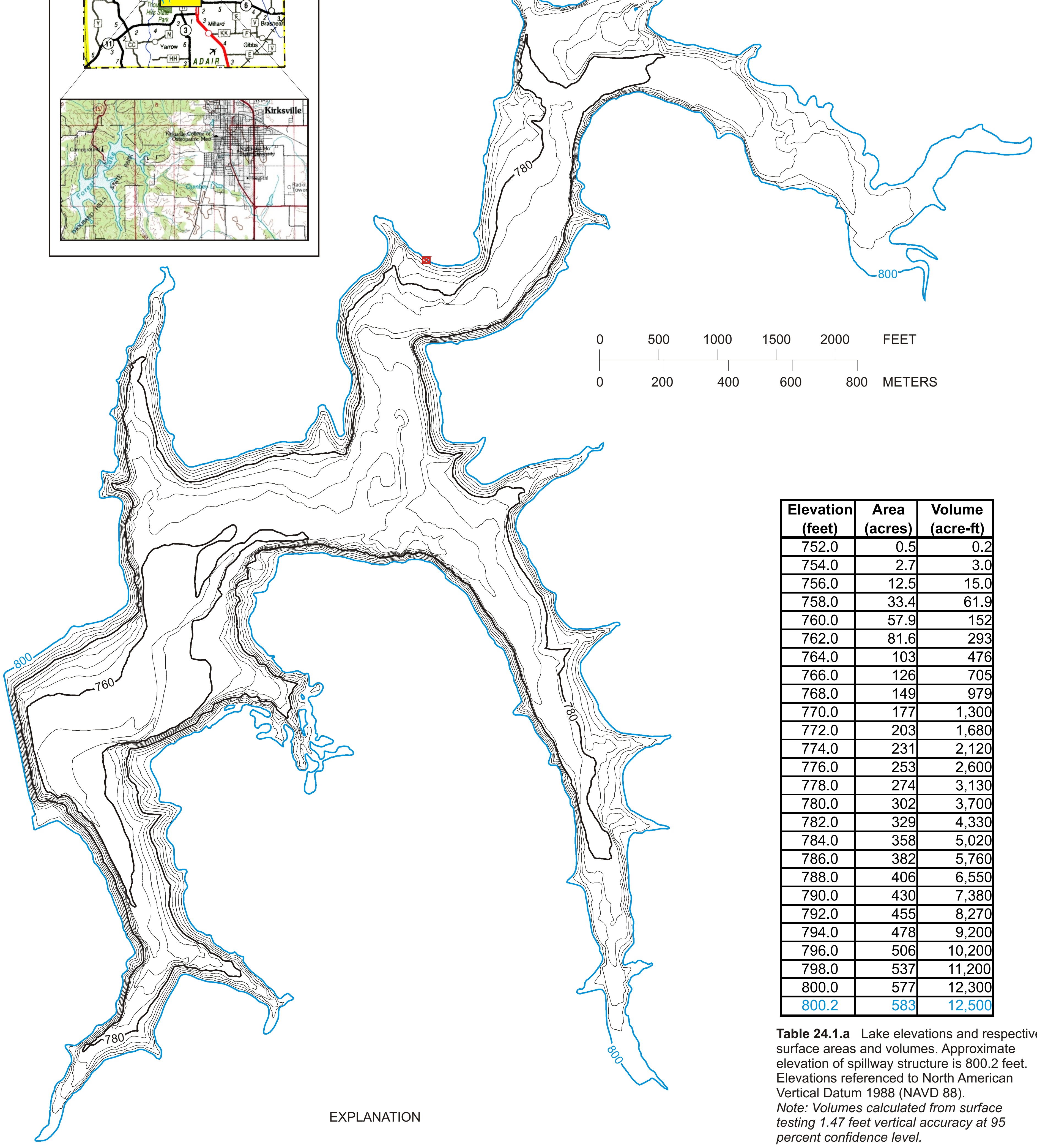
[DEMAND]

The demands from Forest Lake and Hazel Creek Lake were determined to be 2.060 million gallons per day and 0.840 million gallons respectively for a total of 2.900 million gallons per day.

City records reported to Missouri Department of Natural Resources ‘Major water users data base’ were used to determined demand (figure 24.2). In year 2000 Kirksville reported using 1,058,634,000 gallons of water for and average demand of 2.900 million gallons per day.

FOREST LAKE





Elevation (feet)	Area (acres)	Volume (acre-ft)
752.0	0.5	0.2
754.0	2.7	3.0
756.0	12.5	15.0
758.0	33.4	61.9
760.0	57.9	152
762.0	81.6	293
764.0	103	476
766.0	126	705
768.0	149	979
770.0	177	1,300
772.0	203	1,680
774.0	231	2,120
776.0	253	2,600
778.0	274	3,130
780.0	302	3,700
782.0	329	4,330
784.0	358	5,020
786.0	382	5,760
788.0	406	6,550
790.0	430	7,380
792.0	455	8,270
794.0	478	9,200
796.0	506	10,200
798.0	537	11,200
800.0	577	12,300
800.2	583	12,500

Table 24.1.a Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 800.2 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.47 feet vertical accuracy at 95 percent confidence level.

EXPLANATION

—780— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 4 feet. Contours tested 2.92 feet vertical accuracy at 95 percent confidence level.

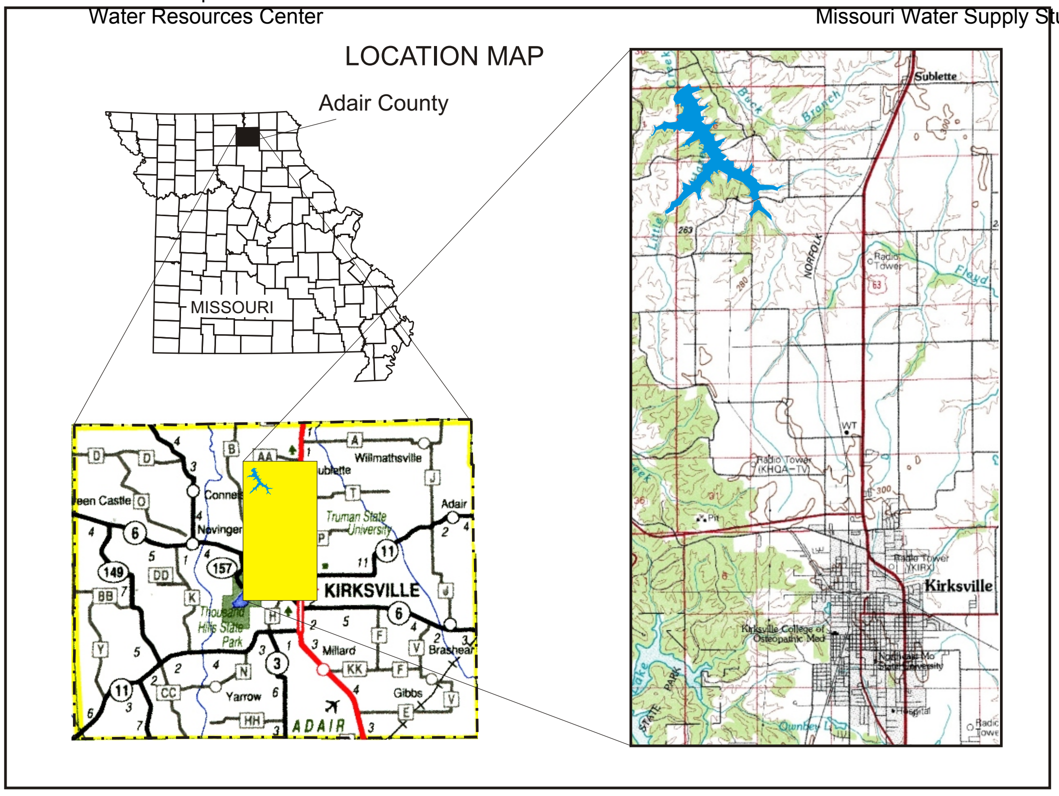
—800— WATER SURFACE—Shows approximate elevation of water surface (actual was 800.2 feet), March 1-2, 2005 (table 23.1.a).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located 80 feet southeast of boat ramp on retaining wall. Elevation 801.8 feet.

Figure 24.1.a

Figure 24.1.a Bathymetric map and table of areas/volumes of the Forest Lake near Kirksville, Missouri.

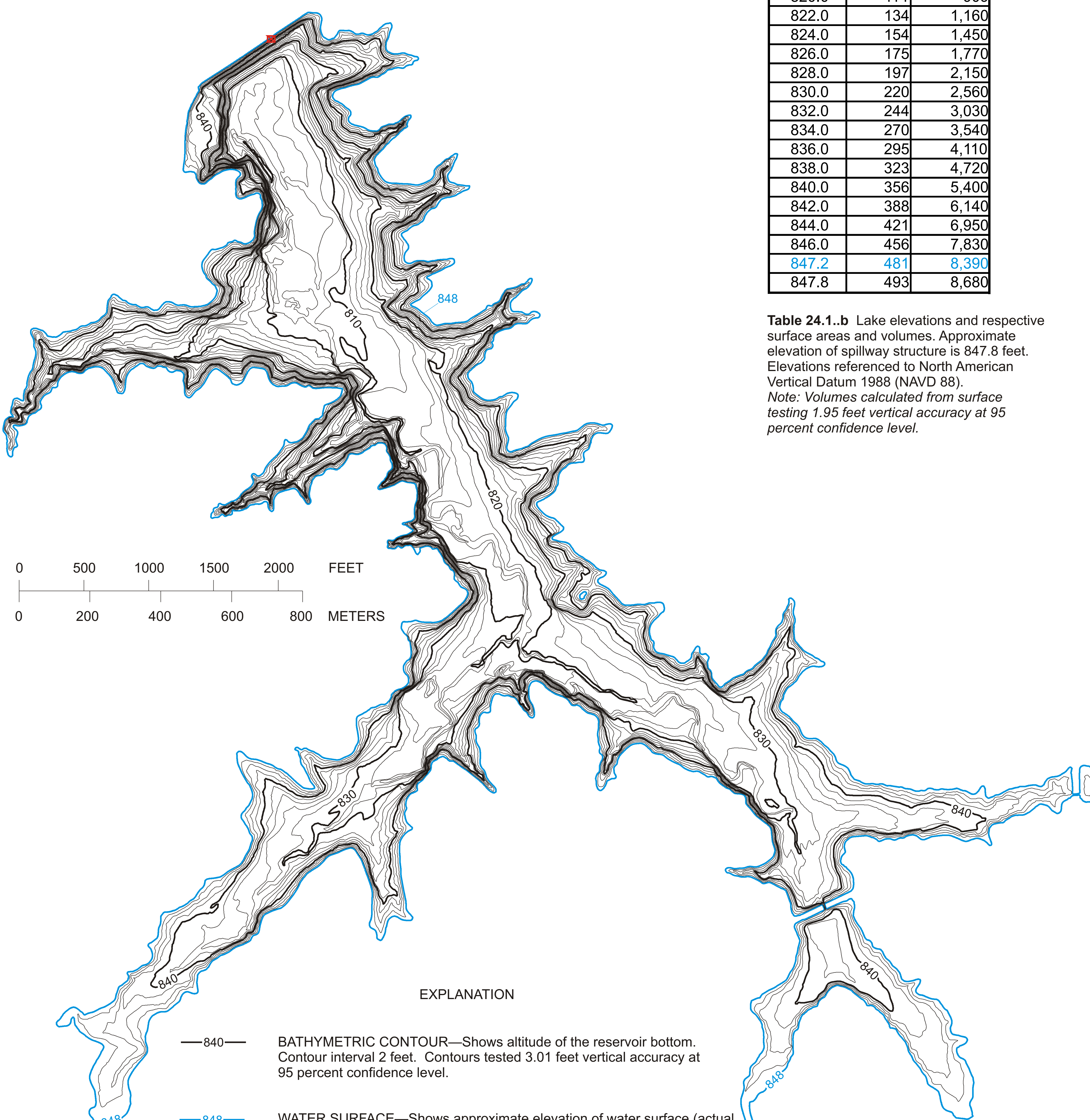
In cooperation with Missouri Department of Natural Resources



HAZEL CREEK LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
800.0	0.2	0.1
802.0	0.9	1.0
804.0	4.3	5.0
806.0	16.1	23.7
808.0	30.1	71.9
810.0	42.0	143
812.0	54.6	240
814.0	69.8	365
816.0	83.2	518
818.0	97.4	698
820.0	114	909
822.0	134	1,160
824.0	154	1,450
826.0	175	1,770
828.0	197	2,150
830.0	220	2,560
832.0	244	3,030
834.0	270	3,540
836.0	295	4,110
838.0	323	4,720
840.0	356	5,400
842.0	388	6,140
844.0	421	6,950
846.0	456	7,830
847.2	481	8,390
847.8	493	8,680

Table 24.1..b Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 847.8 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.95 feet vertical accuracy at 95 percent confidence level.



EXPLANATION

840 BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Contours tested 3.01 feet vertical accuracy at 95 percent confidence level.

848 WATER SURFACE—Shows approximate elevation of water surface (actual was 847.2 ft), March 2-4, 2005 (table 23.1.b).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on south side of drop-box spillway structure. Elevation 855.1 feet.

Figure 24.1.b

USGS
science for a changing world

Figure24.1.b Bathymetric map and table of areas/volumes of the Hazel Creek Lake near Kirksville, Missouri.

In cooperation with Missouri Department of Natural Resources

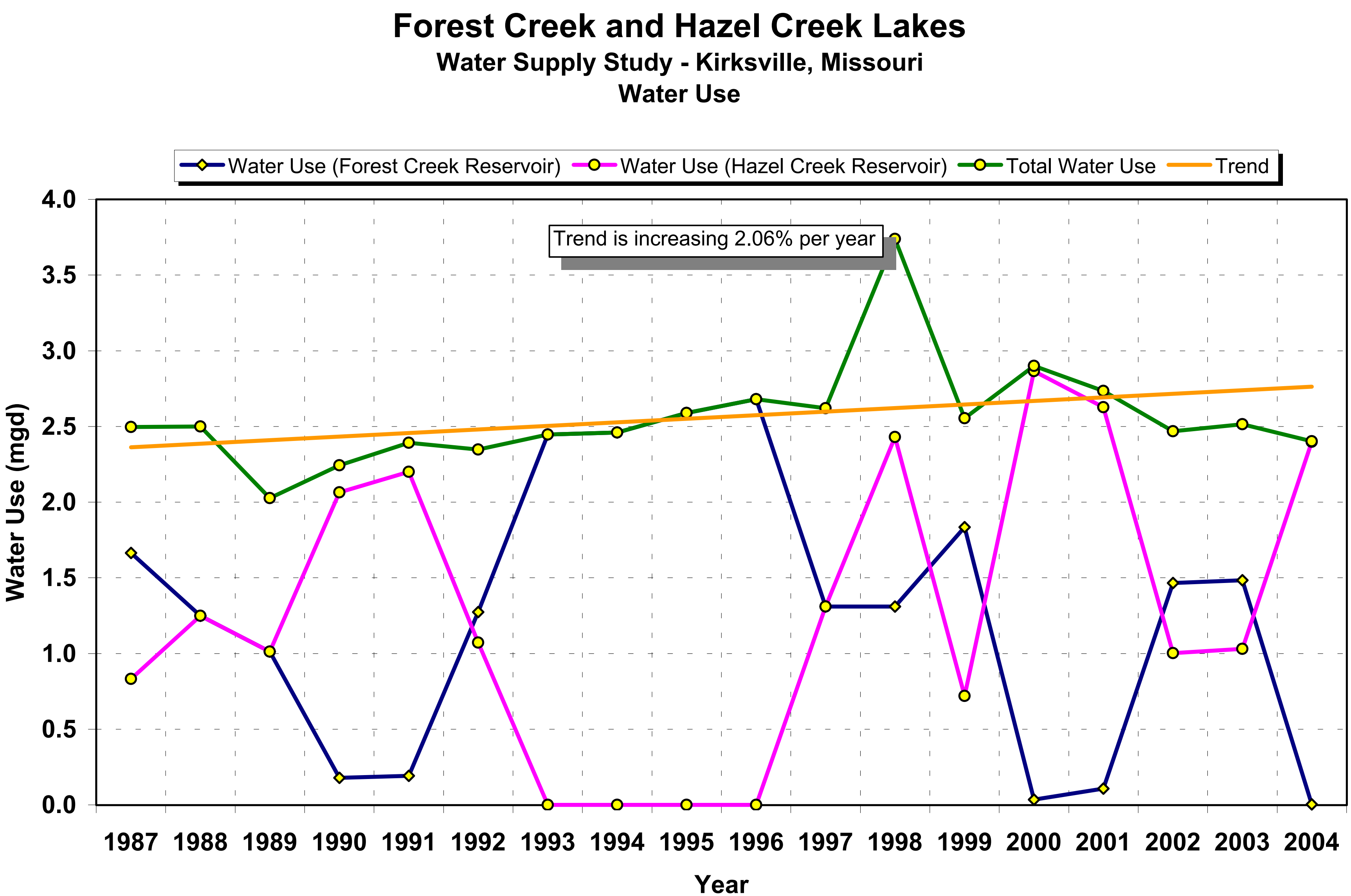

Forest Creek and Hazel Creek Lakes
Water Supply Study - Kirksville, Missouri
Water Use
Water Use (Forest Creek Reservoir)
Water Use (Hazel Creek Reservoir)
Total Water Use
Trend
Trend is increasing 2.06% per year
Water Use (mgd)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Year

figure 24.2

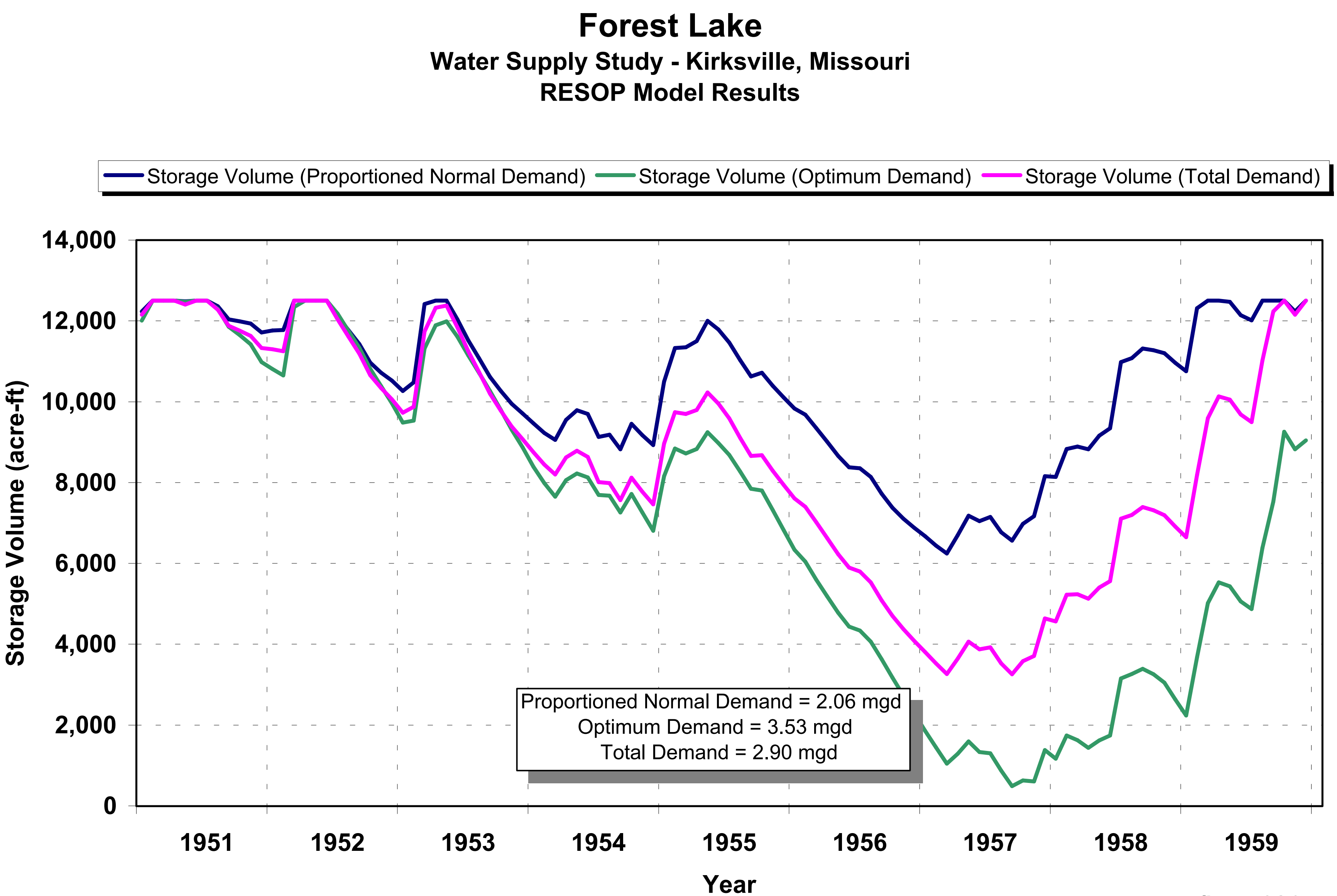

Forest Lake
Water Supply Study - Kirksville, Missouri
RESOP Model Results
Storage Volume (Proportioned Normal Demand)
Storage Volume (Optimum Demand)
Storage Volume (Total Demand)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Storage Volume (acre-ft)
Proportioned Normal Demand = 2.06 mgd
Optimum Demand = 3.53 mgd
Total Demand = 2.90 mgd
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

figure 24.3.a

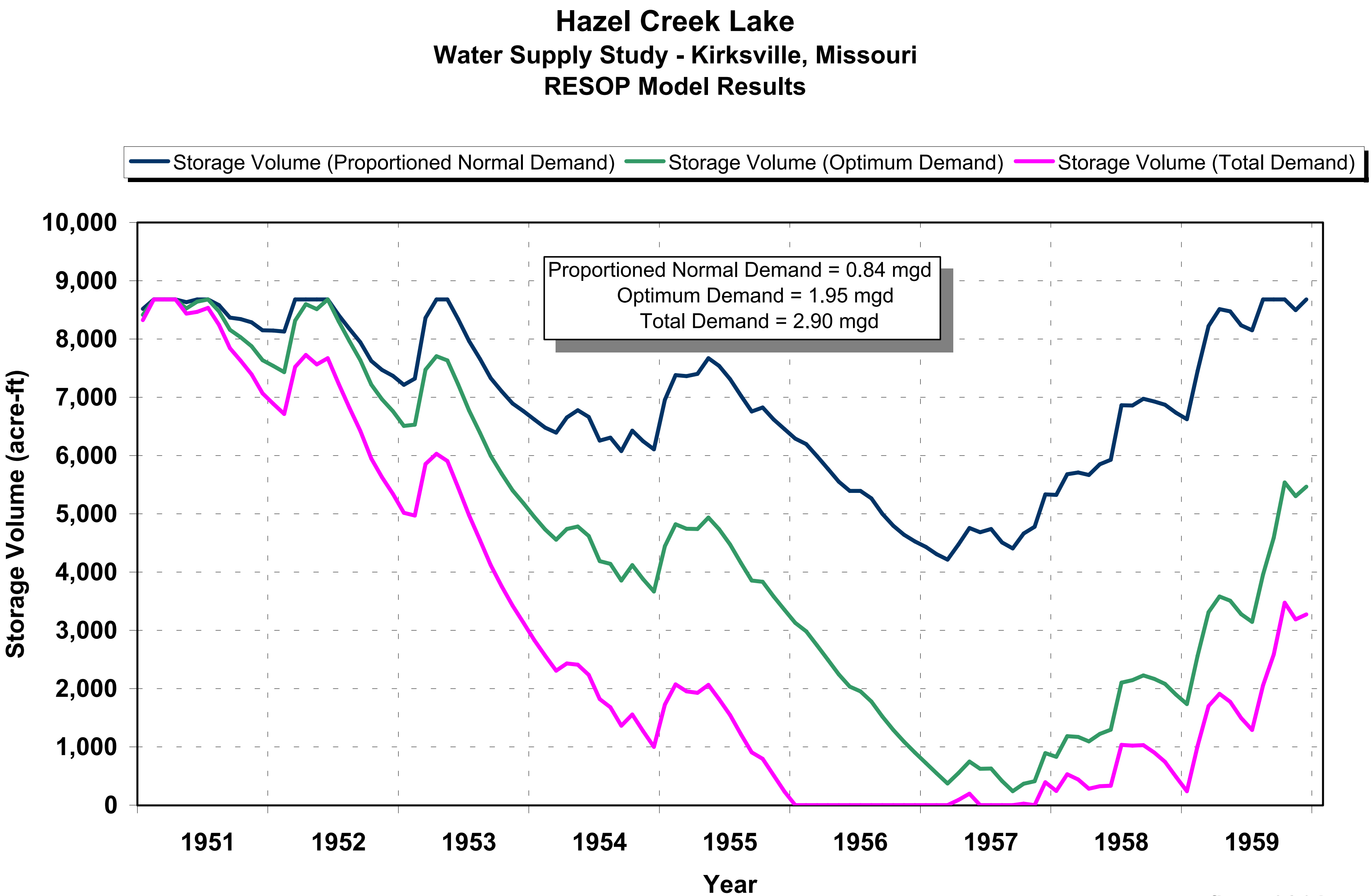

Hazel Creek Lake
Water Supply Study - Kirksville, Missouri
RESOP Model Results
Storage Volume (Proportioned Normal Demand)
Storage Volume (Optimum Demand)
Storage Volume (Total Demand)
Proportioned Normal Demand = 0.84 mgd
Optimum Demand = 1.95 mgd
Total Demand = 2.90 mgd
Storage Volume (acre-ft)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

figure 24.3.b

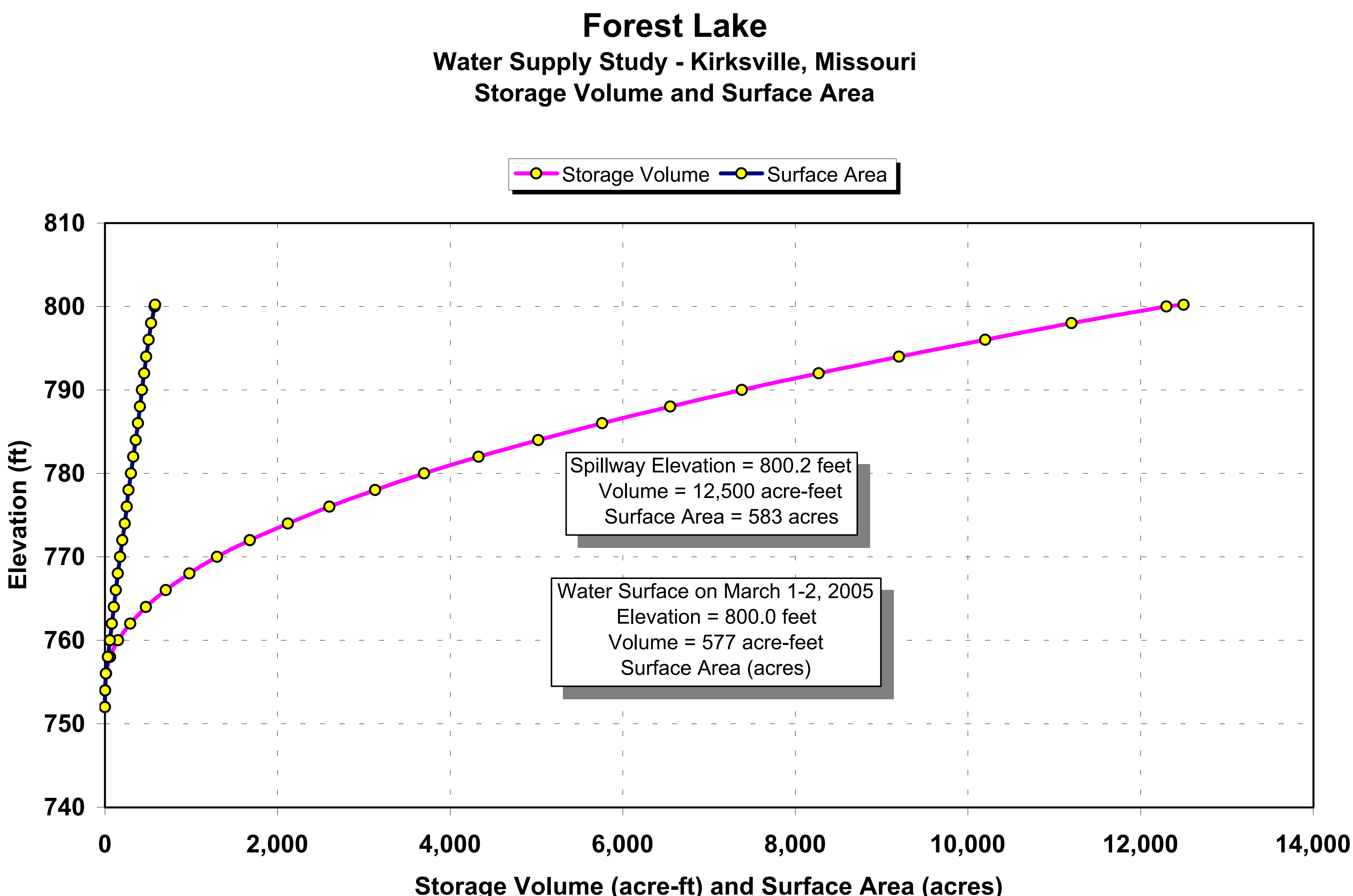

Forest Lake
Water Supply Study - Kirksville, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
810
800
790
780
770
760
750
740
Elevation (ft)
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 800.2 feet
Volume = 12,500 acre-feet
Surface Area = 583 acres
Water Surface on March 1-2, 2005
Elevation = 800.0 feet
Volume = 577 acre-feet
Surface Area (acres)

Figure 24.4.a

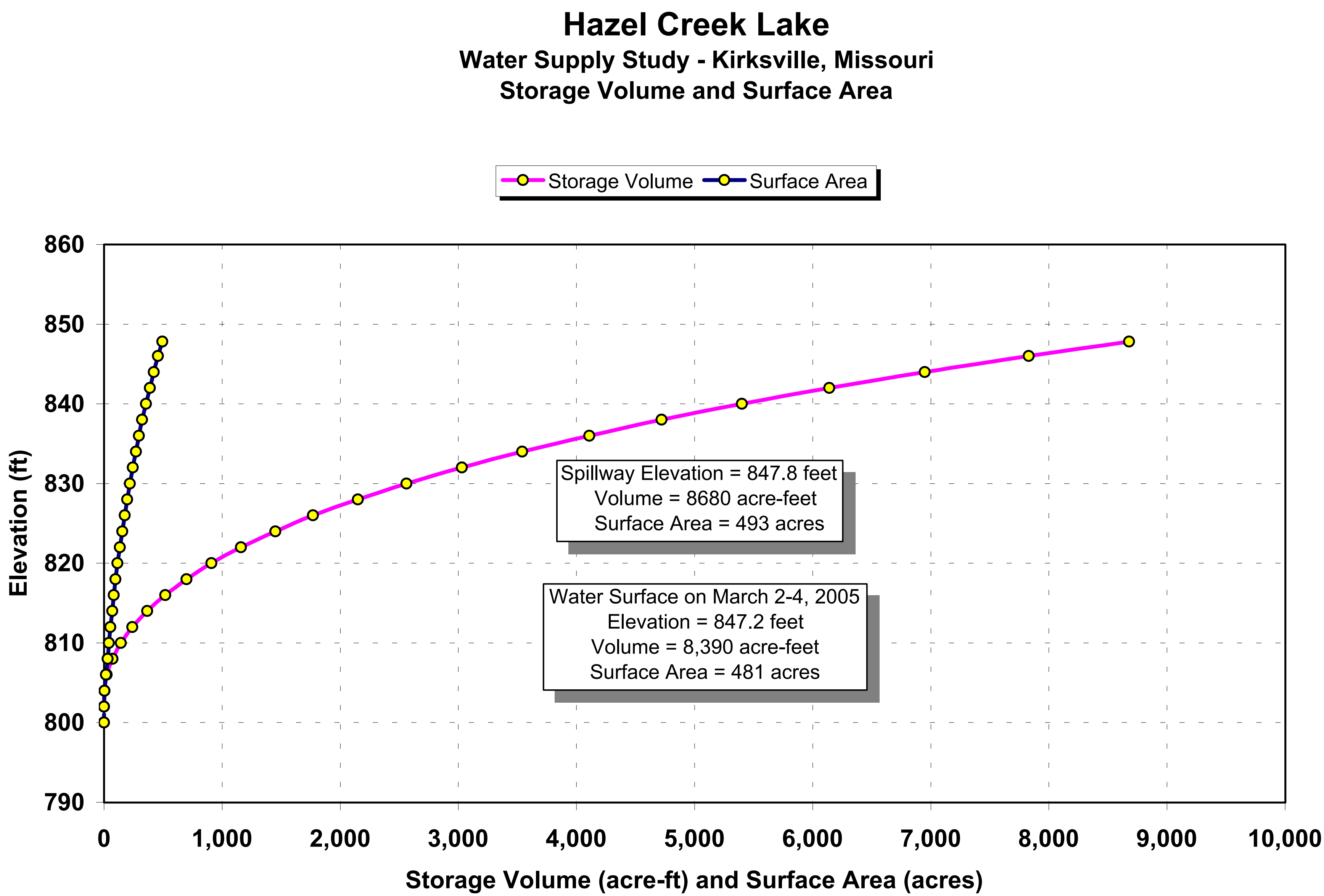

Hazel Creek Lake
Water Supply Study - Kirksville, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 847.8 feet
Volume = 8680 acre-feet
Surface Area = 493 acres
Water Surface on March 2-4, 2005
Elevation = 847.2 feet
Volume = 8,390 acre-feet
Surface Area = 481 acres
Elevation (ft)
860
850
840
830
820
810
800
790
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
Storage Volume (acre-ft) and Surface Area (acres)

Figure 24.4.b

Lake Viking Reservoir
Water Supply Study – Lake Viking, Missouri
Drought Assessment Analysis
Daviess County Public Water Supply #3

I. Overview

Lake Viking (figure 25.1) is located in central Daviess County in northwest Missouri. This lake is privately owned and supplies water to the homeowners around the lake. The lake is located on South Big Creek, a tributary to Grand River. The lake is approximately 3 miles west of Gallatin (figure 25.1). It is primarily used for residential and recreation uses for those owning property around the lake. The homeowners association owns and maintains the lake. The drainage area of this 60 feet deep lake is 14.13 square miles.

The homeowners of Lake Viking draw water directly from the reservoir to the treatment facility. Lake Viking is not considered a major water user. As a result they have not been reporting their water use to Missouri Department of Natural Resources. The Safe Drinking Water Information System (SDWIS) database indicates they are currently using an average of 50,000 gallon per day.

Current water use is for Daviess Public Water Supply District #3 and they operate the treatment facility with the lake being the supply source. The water supply district is for those within the Community property. In year 2000 there were approximately 431 homes in the community. Approximately two-thirds are lived in year round with the remaining used for weekend and vacation residences. The safe drinking water information system (SDWIS) indicates they are using about 50,000 gallons per day. The optimized yield for Lake Viking is 2.45 million gallons per day.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Lake Viking Reservoir. The model assumes that ‘Normal’ demand for Lake Viking is 50,000 gallons per day and that ‘Optimum’ yield from the lake is 2.46 million gallons per day. Figure 25.3 illustrates these relationships.

II. Drought Assessment Summary

The Lake Viking Reservoir is able to supply the residents with adequate water. When the demand value of 50,000 gallons per day is applied to the reservoir during the drought of the 1950’s, volume in the reservoir would be reduced to 9300 acre-feet in March and April 1957. The reservoir is capable of supplying 2.46 million gallons per day.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Lake Viking Reservoir conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on March 22 and 23, 2006. Surface area of the lake and associated storage volume capacities are illustrated in figure 25.4.

Lake Viking Reservoir Physical Data

Lake Viking			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
804.0	0.07	0.14	
806.0	2.1	3.0	
808.0	4.4	10.0	
810.0	9.4	22.4	
812.0	20.7	51.8	
814.0	30.6	104	
816.0	39.7	174	
818.0	48.4	261	
820.0	61.9	371	
822.0	78.2	510	
824.0	91.2	680	
826.0	105	876	
828.0	119	1,100	
830.0	131	1,350	
832.0	145	1,620	
834.0	160	1,930	
836.0	174	2,260	
838.0	190	2,630	
840.0	208	3,030	
842.0	225	3,460	
844.0	247	3,930	
846.0	269	4,450	
848.0	291	5,010	
850.0	317	5,610	
852.0	341	6,270	
854.0	367	6,980	
856.0	394	7,740	
858.0	424	8,550	
860.0	468	9,440	
862.0	503	10,400	
864.0	534	11,500	
865.1	553	12,000	Lake Conditions on March 22 and 23, 2006
871.4	660	15,500	Top of Dam – area and volume extrapolated
Principal Spillway Elevation = 865.0 feet			

[LIMITS]

Maximum storage……………………………………………………………..12,000 acre-feet
Minimum Pool storage…………………………………………………………1000 acre-feet
Drainage basin size…………………………………………………………..14.13 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Lake Viking is approximately 3.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation values for the drought of record were obtained from the Gallatin, Missouri gauge.

Average precipitation in Gallatin was 44.08 inches between 1951 and 2001. Precipitation values for the drought of record were obtained from Gallatin, Missouri (approximately 3 miles west of Gallatin). The most severe drought occurred between 1953 and 1957 with annual precipitation values in Chillicothe of 20.07 inches, 33.55 inches, 28.27 inches, 27.88 inches, and 42.38 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the East Fork Big Creek stream gauge at Bethany Missouri which is a tributary of the Grand River, located approximately 20 miles north of Lake Viking. The drainage area monitored by this stream gauge covers approximately 95 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Lake Viking, individual storm events were considered. Antecedent rainfall was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

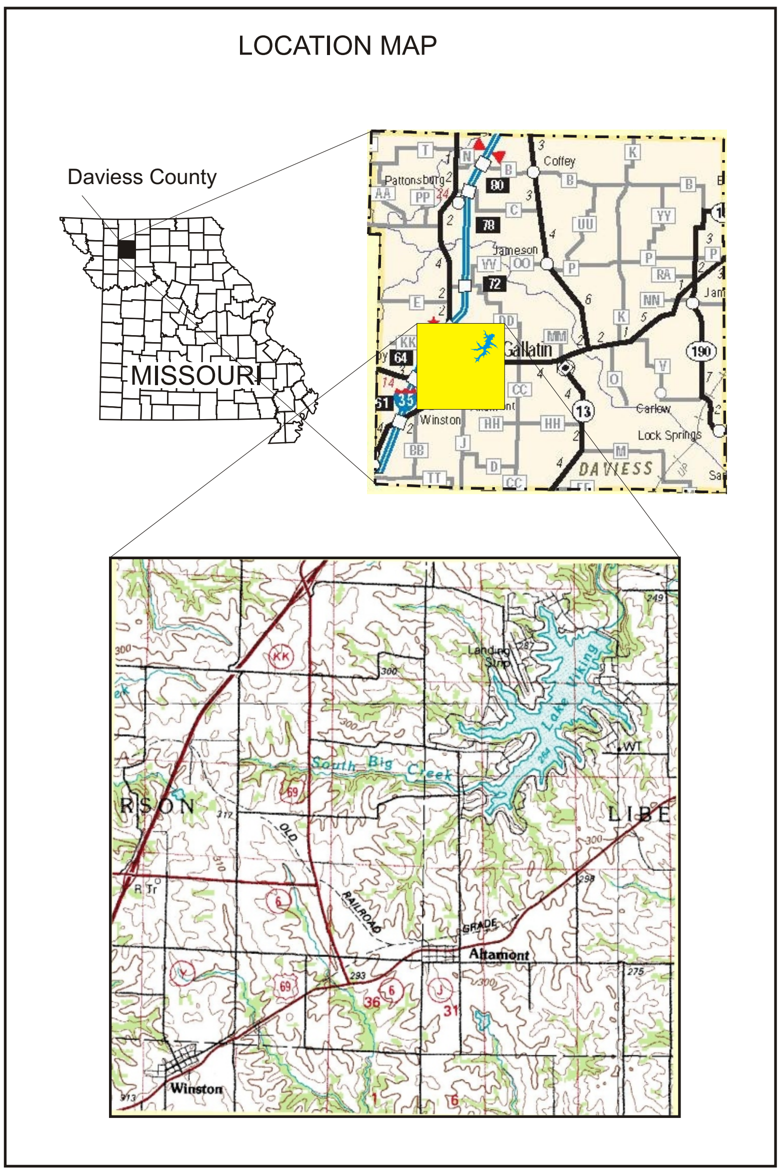
[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Lake Viking Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

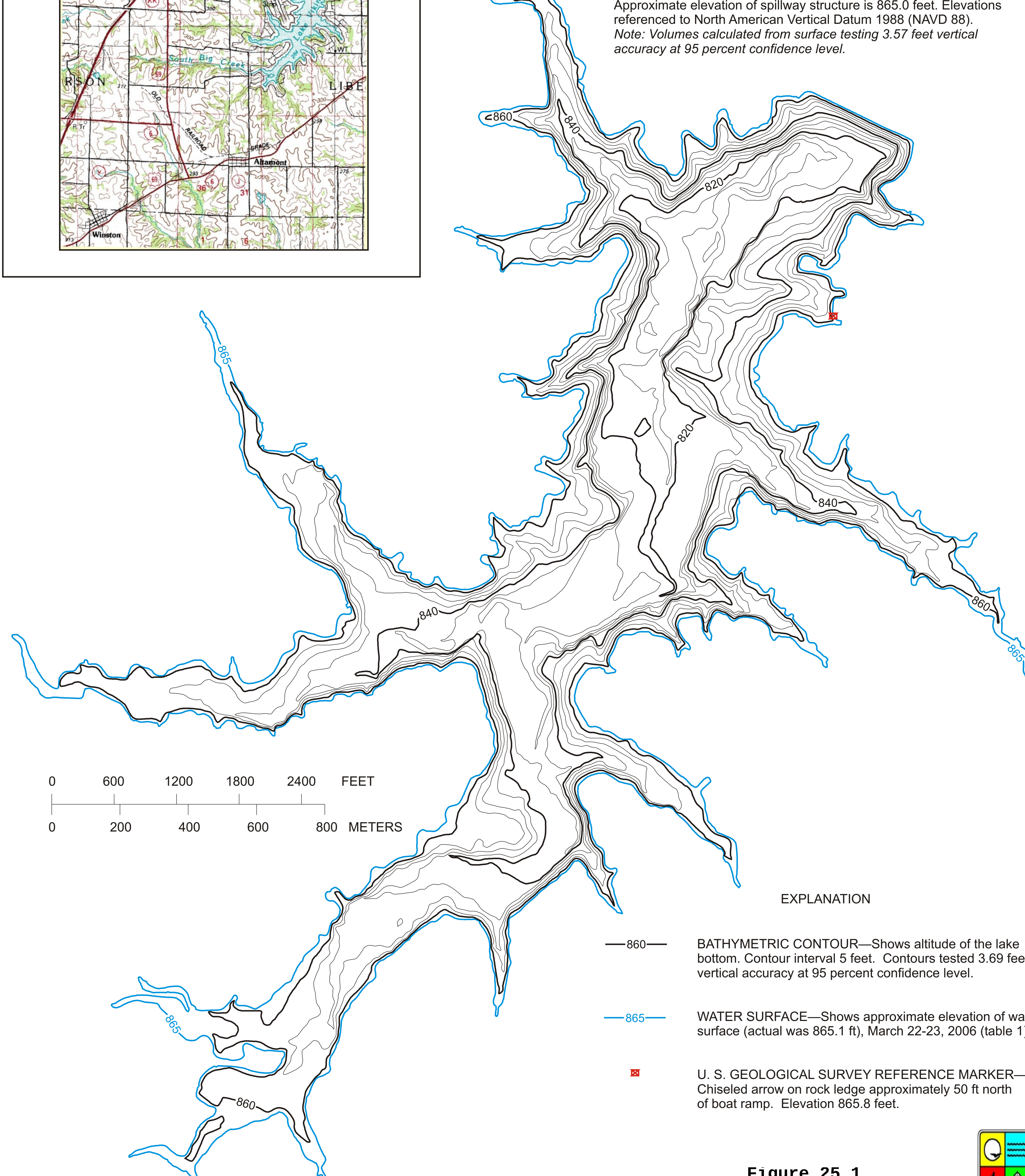
The demand used for Lake Viking's analysis came from Missouri safe drinking water information system (SDWIS). They reported Lake Viking is 50,000 gallons per day which was used for this analysis..

LAKE VIKING



Elevation (feet)	Area (acres)	Volume (acre-ft)	Elevation (feet)	Area (acres)	Volume (acre-ft)
804.0	0.7	0.7	836.0	174	2,260
806.0	2.1	3.0	838.0	190	2,630
808.0	4.4	10.0	840.0	208	3,030
810.0	9.4	22.4	842.0	225	3,460
812.0	20.7	51.8	844.0	247	3,930
814.0	30.6	104	846.0	269	4,450
816.0	39.7	174	848.0	291	5,010
818.0	48.4	261	850.0	317	5,610
820.0	61.9	371	852.0	341	6,270
822.0	78.2	510	854.0	367	6,980
824.0	91.2	680	856.0	394	7,740
826.0	105	876	858.0	424	8,550
828.0	119	1,100	860.0	468	9,440
830.0	131	1,350	862.0	503	10,400
832.0	145	1,620	864.0	534	11,500
834.0	160	1,930	865.1	553	12,000

Table 25.1 Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 865.0 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 3.57 feet vertical accuracy at 95 percent confidence level.



EXPLANATION

860 BATHYMETRIC CONTOUR—Shows altitude of the lake bottom. Contour interval 5 feet. Contours tested 3.69 feet vertical accuracy at 95 percent confidence level.

865 WATER SURFACE—Shows approximate elevation of water surface (actual was 865.1 ft), March 22-23, 2006 (table 1).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on rock ledge approximately 50 ft north of boat ramp. Elevation 865.8 feet.

Figure 25.1

In cooperation with Missouri Department of Natural Resources

Figure 24.1 Bathymetric map and table of areas/volumes of the Lake Viking near Gallatin, Missouri.

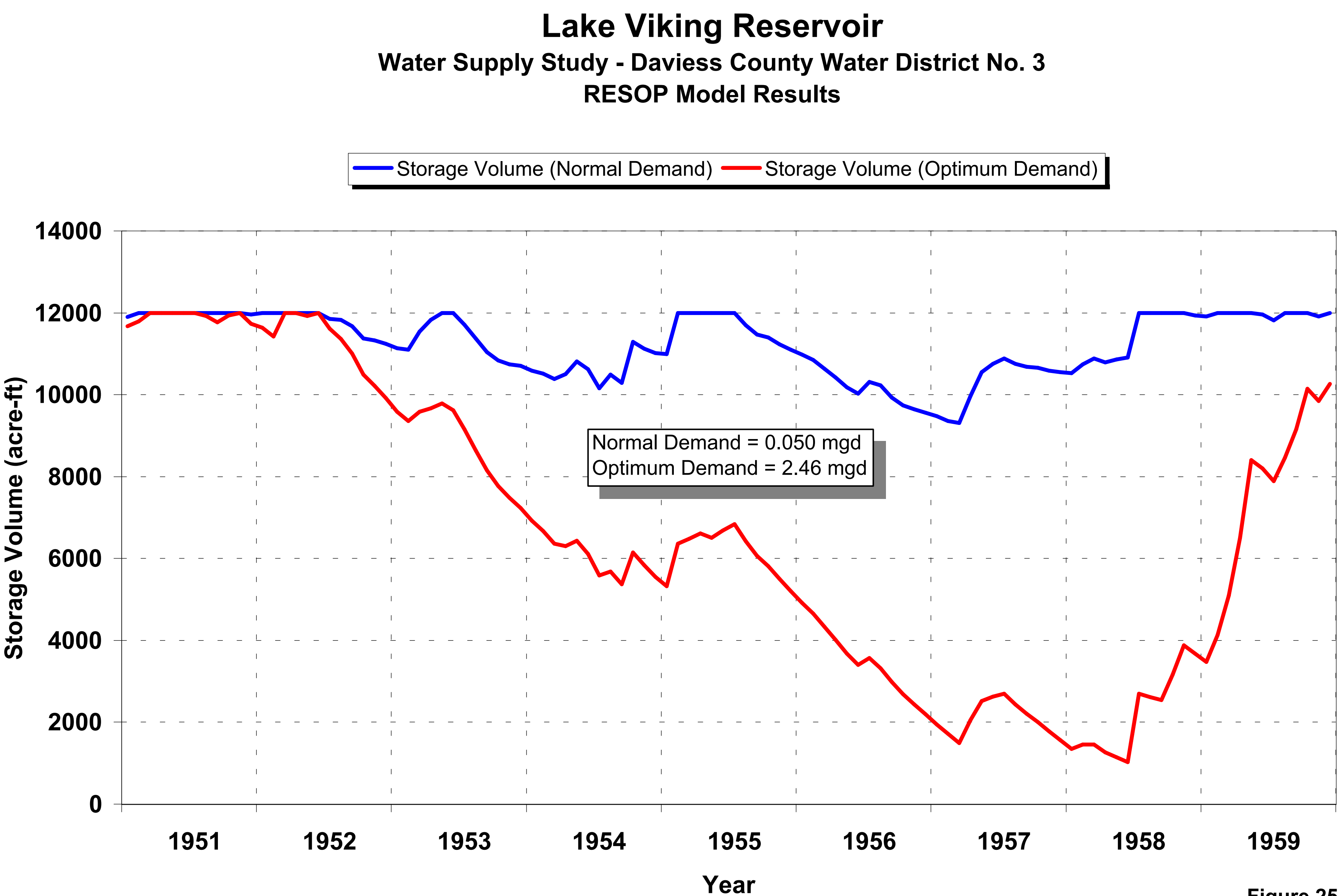

Lake Viking Reservoir
Water Supply Study - Daviess County Water District No. 3
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 0.050 mgd
Optimum Demand = 2.46 mgd
Storage Volume (acre-ft)
14000
12000
10000
8000
6000
4000
2000
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 25.3

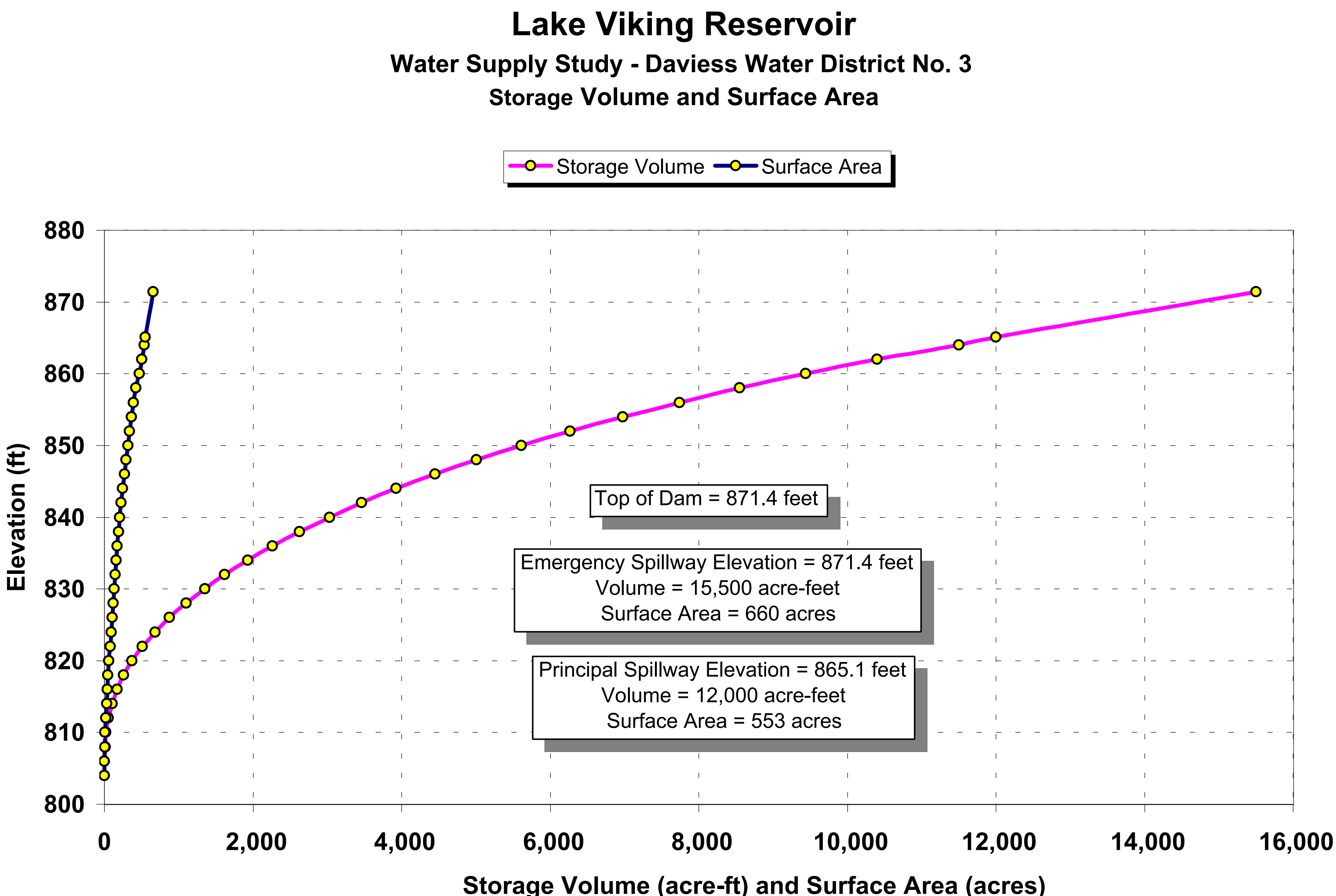

Lake Viking Reservoir
Water Supply Study - Daviess Water District No. 3
Storage Volume and Surface Area
Storage Volume
Surface Area
880
870
860
850
840
830
820
810
800
Elevation (ft)
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
Storage Volume (acre-ft) and Surface Area (acres)
Top of Dam = 871.4 feet
Emergency Spillway Elevation = 871.4 feet
Volume = 15,500 acre-feet
Surface Area = 660 acres
Principal Spillway Elevation = 865.1 feet
Volume = 12,000 acre-feet
Surface Area = 553 acres

Figure 25.4

Lamar Reservoir
Water Supply Study – Lamar, Missouri
Drought Assessment Analysis

I. Overview

Lamar Reservoir (figure 26.1) is located in central Barton County, west central Missouri and less than one mile southeast of the City of Lamar on a tributary to Spring River. Lamar Reservoir is the primary source of water for the City of Lamar. The Lamar Reservoir serves a population of approximately 4,425 with an estimated water demand of 0.50 million gallons per day according to the 2008 Census of Missouri Public Water Systems maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources.

The City of Lamar draws water directly from the reservoir to the treatment facility, and the reservoir, itself, can be supplemented with water from one groundwater well owned by the city. Historical demand on the water supply system in 2001 was reported to be 480,000 gallons per day, which is the demand value, used in this model. Figure 26.2 illustrates historical water demand on the Lamar Reservoir and their one well.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Lamar Reservoir. Although one groundwater well is available to supplement this water supply, the contribution of this well to available supplies was not considered within the context of this model. The model assumes that 'Normal' demand for Lamar is 480,000 gallons per day and that 'Optimum' yield from the lake is 427,000 gallons per day. Figure 26.3 illustrates these relationships.

II. Drought Assessment Summary

The Lamar Reservoir is at risk of not meeting the community's demand for water during times of drought unless there is an additional source of water. The 2001 demand on the reservoir was approximately 480,000 gallons per day, and when this demand value is applied to the reservoir during the drought of record in the 1950's, water deficits would have occurred in July, August and September 1954. The estimated optimum yield from Lamar Reservoir is 427,000 gallons per day without additional water sources. The groundwater well owned by the City of Lamar is capable of pumping an average of 340,000 gallons per day supplementing Lamar Lake's supply.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Lamar Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on May 22, 2002. Surface area of the lake and associated storage volume capacities are illustrated in figure 26.4.

Lamar Lake Physical Data

Lamar Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
930.0	0.1	0.1	
932.0	0.1	0.3	
934.0	1.5	1.0	
936.0	8.4	10.4	
938.0	20.0	37.4	
940.0	36.2	93.4	
942.0	50.6	180.1	
944.0	65.5	296.2	
946.0	80.6	441.9	
948.0	95.7	617.8	
950.0	112.0	825.6	
952.0	126.0	1,063.6	
954.0	142.0	1,329.9	
955.7	156.4	1,582.5	Spillway and Lake Condition on May 22, 2002

[LIMITS]

Maximum storage ....1,582 acre-feet
Minimum storage ....35.0 acre-feet
Drainage basin size ....4.77 Square Miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Lamar Lake is approximately 2.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Rainfall data came from the Lamar, Mo. rain gauge for the period 1951 through 1959.

Average annual rainfall is 37.2 inches. Annual rainfall for 1953 through 1957 is 21.45, 35.52, 34.61, 23.14, and 48.20 inches.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Cedar Creek stream gauge near pleasant View. When this regional runoff value is inconsistent with precipitation values recorded for Lamar, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Lamar Reservoir due to evaporation. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

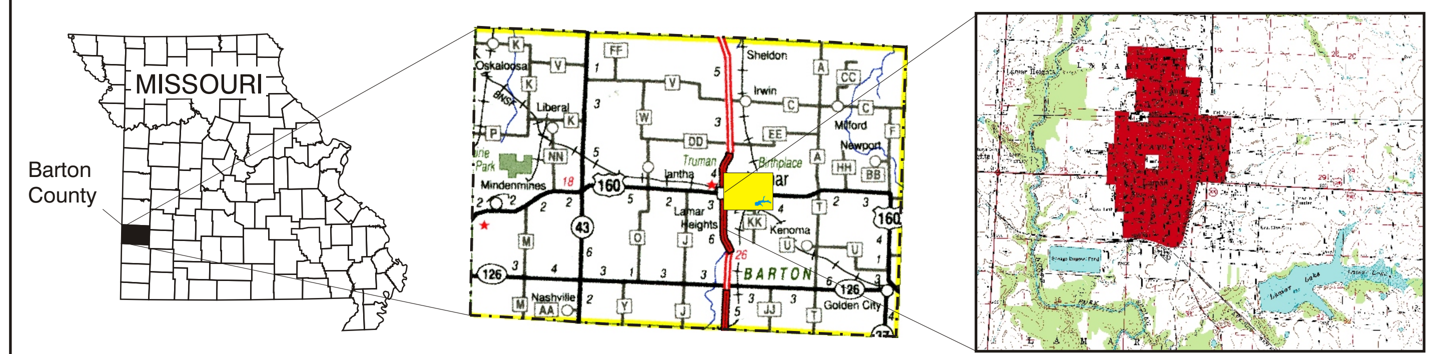
Values for water usage by Lamar are illustrated in figure 26.2. Between 1989 and 2001, water demand in Lamar was fairly constant at 0.480 million gallons per day which was the value used for this analysis. In 1996 they used the unusually large amount of water of 0.70 million gallons per day. Optimum demand (yield) from Lamar Reservoir without an additional source of water (Lamar's well) is 0.427 million gallons per day.

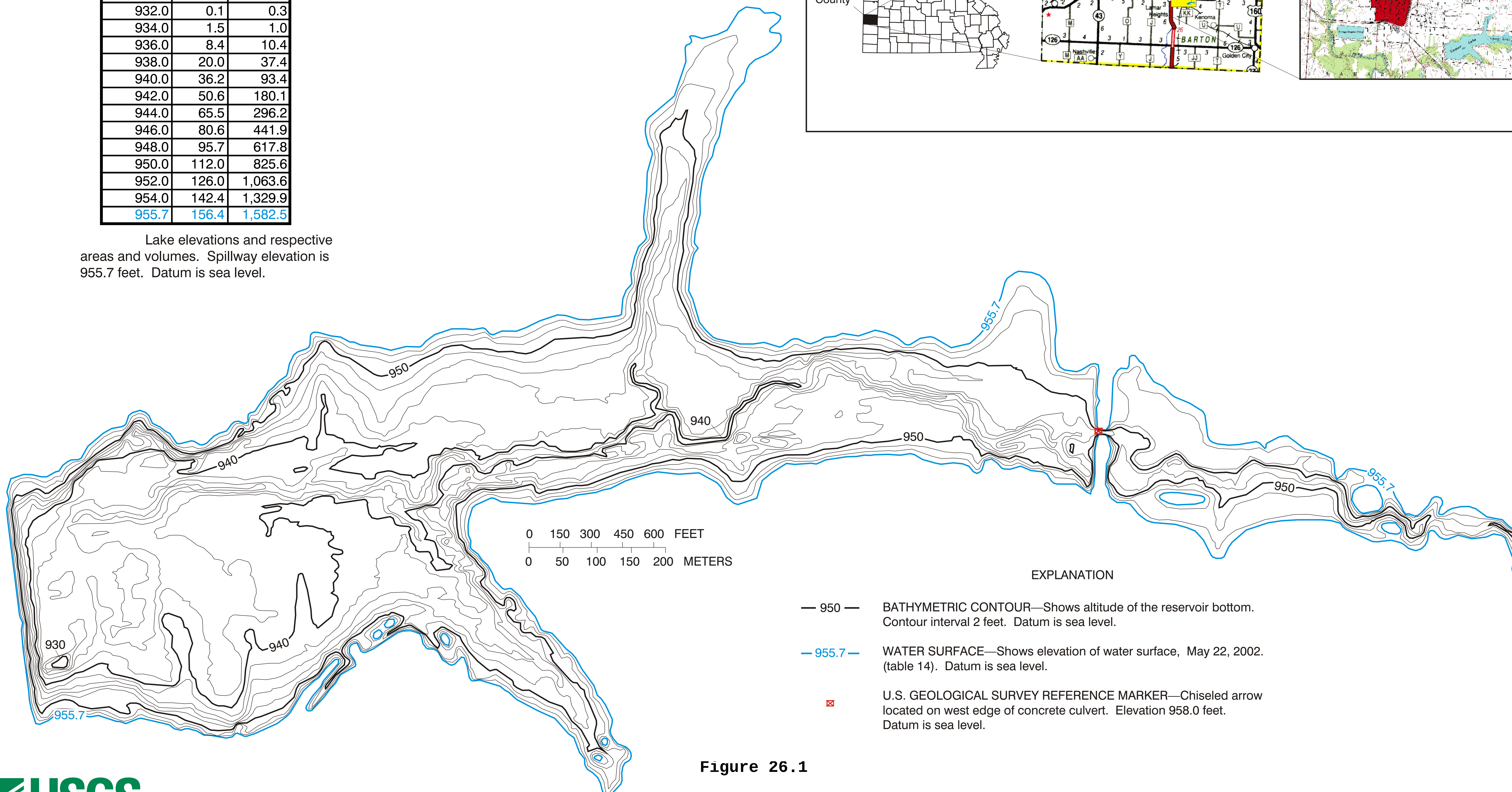
LAMAR LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
930.0	0.1	0.1
932.0	0.1	0.3
934.0	1.5	1.0
936.0	8.4	10.4
938.0	20.0	37.4
940.0	36.2	93.4
942.0	50.6	180.1
944.0	65.5	296.2
946.0	80.6	441.9
948.0	95.7	617.8
950.0	112.0	825.6
952.0	126.0	1,063.6
954.0	142.4	1,329.9
955.7	156.4	1,582.5

Lake elevations and respective areas and volumes. Spillway elevation is 955.7 feet. Datum is sea level.

LOCATION MAP





0 150 300 450 600 FEET
0 50 100 150 200 METERS

EXPLANATION

— 950 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

— 955.7 — WATER SURFACE—Shows elevation of water surface, May 22, 2002. (table 14). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west edge of concrete culvert. Elevation 958.0 feet. Datum is sea level.

USGS
science for a changing world

Figure 26.1

Bathymetric map and table of areas/volumes of Lamar Lake near Lamar, Missouri.

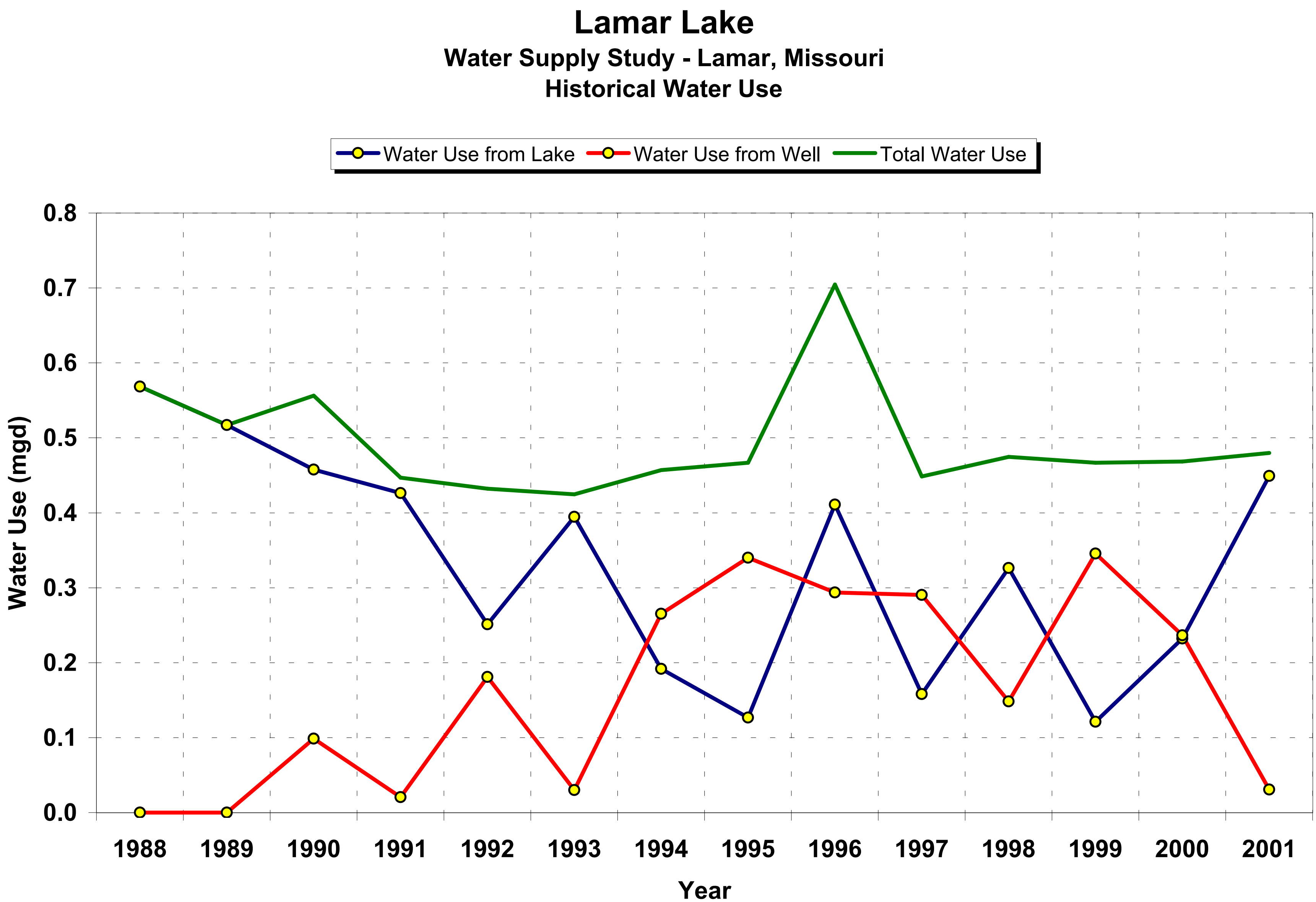

Lamar Lake
Water Supply Study - Lamar, Missouri
Historical Water Use
Water Use from Lake
Water Use from Well
Total Water Use
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Water Use (mgd)
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 26.2

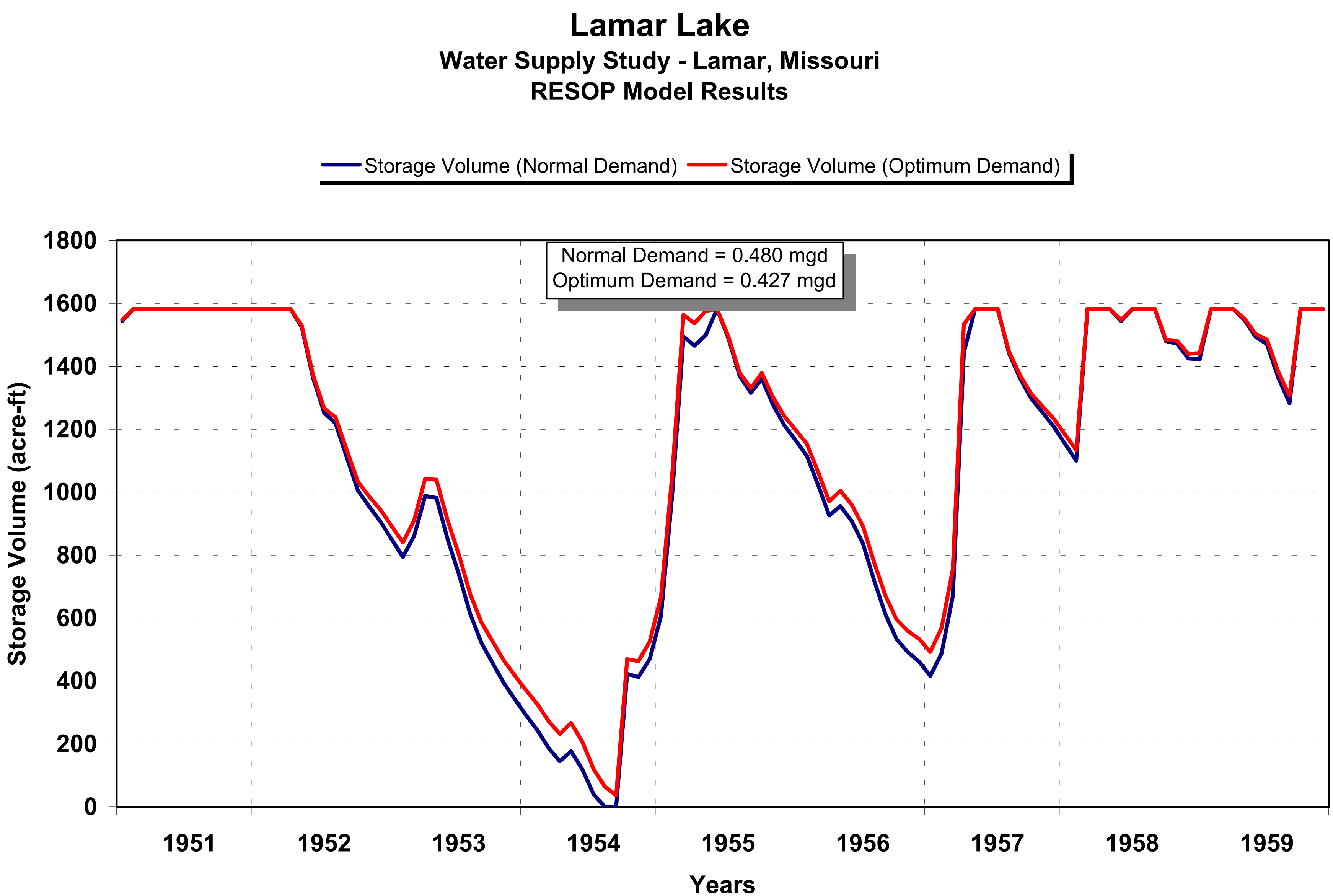

Lamar Lake
Water Supply Study - Lamar, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 0.480 mgd
Optimum Demand = 0.427 mgd
1800
1600
1400
1200
1000
800
600
400
200
0
Storage Volume (acre-ft)
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 26.3

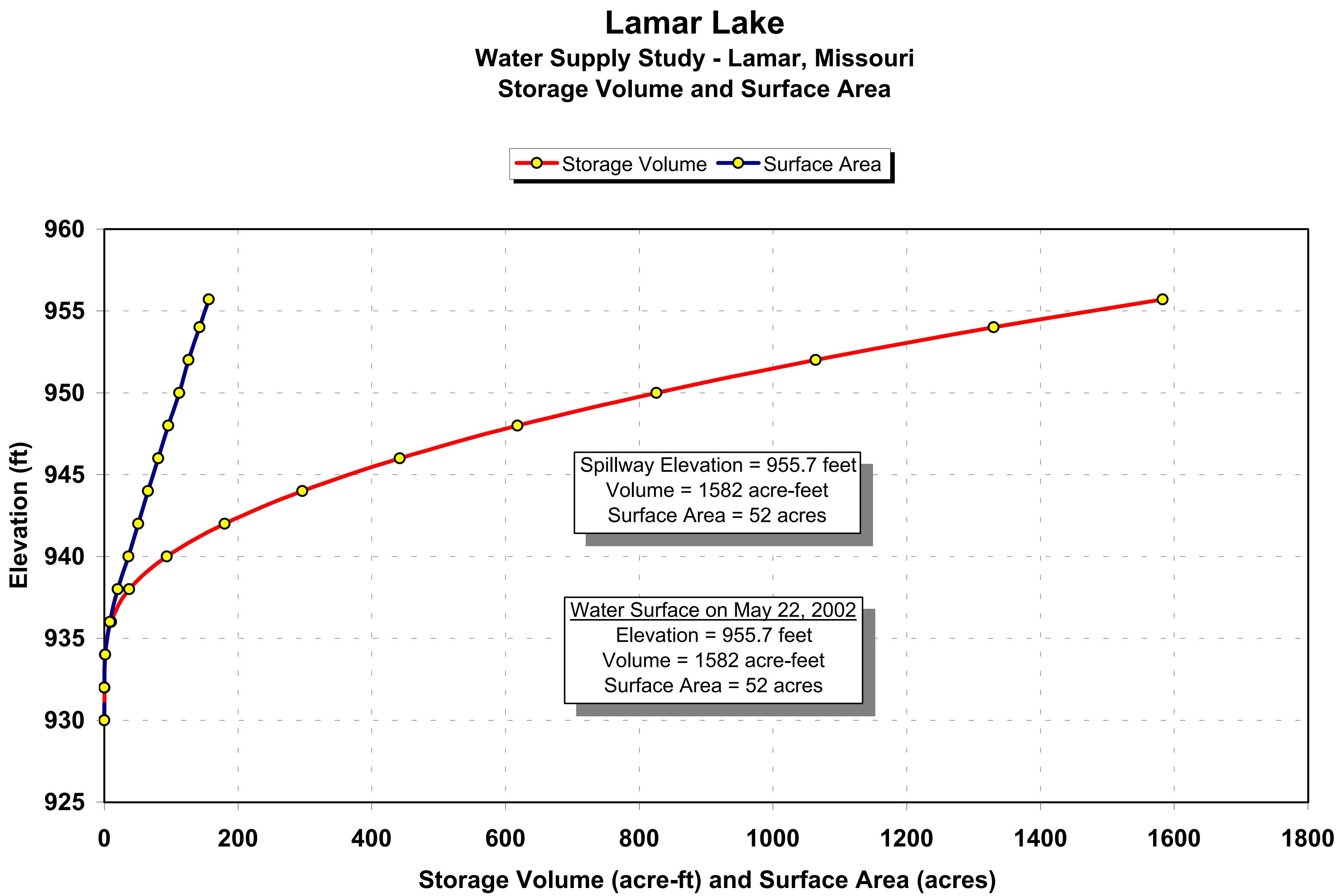

Lamar Lake
Water Supply Study - Lamar, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 955.7 feet
Volume = 1582 acre-feet
Surface Area = 52 acres
Water Surface on May 22, 2002
Elevation = 955.7 feet
Volume = 1582 acre-feet
Surface Area = 52 acres
Elevation (ft)
960
955
950
945
940
935
930
925
0
200
400
600
800
1000
1200
1400
1600
1800
Storage Volume (acre-ft) and Surface Area (acres)

Figure 26.4

Little Otter Creek Lake
Drought Assessment Analysis – Caldwell County Reservoir
PL-566 Multipurpose Lake (MP-1)

I. Overview

Little Otter Creek Reservoir, located in northeast Caldwell County, is designed for flood control, recreation and county water supply. The lake is being planned as a flood prevention and water supply lake through the NRCS small watershed program (PL-566), and is about 70 miles northeast of Kansas City. As of January 23, 2009 the plans have been developed and are waiting completion of final review, land rights have been secured on most tracks of land. Construction funds have not been allocated. This water supply has been planned for county distribution. A release of 60 gallons per minute is planned for in-stream flow uses.

A consulting engineering firm hired by Caldwell County to determine their needs has established demand. The drought of record was during the 1950's. This study evaluated the effects that drought would have on the availability of water supplies.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Three scenarios were modeled for Little Otter Creek Reservoir. The model assumes that 'Normal' demand for Caldwell County would be 1.20 million gallons per day and that 'Optimum' yield from the lake is 1.20 million gallons per day. An additional test assumed the water in the lake to be five feet below the spillway. The next test allowed the water allocated to recreation to be used. Figure 27.3 illustrates these relationships.

II. Drought Assessment Summary

During the planning stage it was projected that 1.2 million gallons per day would meet the needs for water supply. The volume of water supply storage was determined to be 4920 acre- feet. Sensitivity tests were run on the lake's water supply. The first test allowed the recreation storage be used. This resulted in a demand of 1.4 million gallons per day. The second test assumed the lake started five feet below the spillway. The resulting analysis would reduce the optimum demand to 1.0 million gallons per day.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Little Otter Creek Reservoir conducted by the United States Department of Agriculture, Natural Resources

Conservation Service (NRCS). Surface area of the lake and associated storage volume capacities are illustrated in figure 27.4.

Storage allocation:
Sediment…………………………………………….= 804 acre-feet
Recreation………………………………………..= 900 acre-feet
Water Supply…………………………………..= 4,920 acre-feet
Total…………………………………………….= 6,624 acre-feet

Little Otter Reservoir Physical Data

Little Otter Reservoir		
Elevation (feet)	Area (acres)	Volume (acre-feet)
792	0.07	0
796	1.25	2.64
800	3.85	12.84
804	7.77	36.08
808	20.03	91.68
812	32.49	196.72
816	42.55	346.80
820	53.62	539.14
824	84.37	815.12
828	106.48	1196.82
832	125.72	1661.22
836	148.33	2209.32
840	175.01	2856.00
844	207.97	3621.96
848	249.74	4537.38
852	296.72	5630.30
856	358.40	6940.54
860	420.20	8497.74
864	486.10	10,310.34
869	575.00	12,963.09

Principal Spillway Elevation……………………………………….= 855.1 feet.
Emergency Spillway Elevation …………………………….……..= 860.7 feet.

[LIMITS]

Maximum storage……………………………………………….6,624 acre-feet
Minimum storage…………………………………………………..1,704 acre-feet
Drainage basin size…………………………………………..7.54 square miles

Initial storage was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought is in the 1950's. The analysis used in this model is January 1951 and ended December 1959.

[SEEPAGE]

Seepage from Little Otter Creek Reservoir is estimated to be 1.5 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an

earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Rainfall data came from the Hamilton, Missouri weather reporting station.

Average annual precipitation for the 1951 through 2000 is 36.7. The most severe drought occurred between 1953 through 1957 with annual precipitation values of 28.8, 35.7, 28.4, 21.33, and 37.55 inches, respectively. Most of the 1957 rainfall occurred in the last three months of the year. As a result the most critical period of water storage is in the summer of 1957.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from East Fork Big Creek at Bethany. When this regional runoff value is inconsistent with precipitation values for Little Otter Creek Reservoir, daily precipitation rates were considered. Antecedent rainfall was used to estimate soil moisture for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS's) runoff curve number were made to estimate runoff from each storm event (see appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Little Otter Creek Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to derive this value.

[DEMAND]

Water demand for Little Otter Creek Reservoir was estimated to be 1.2 million gallons per day. Caldwell County has hired a consulting engineering firm to determine their needs.

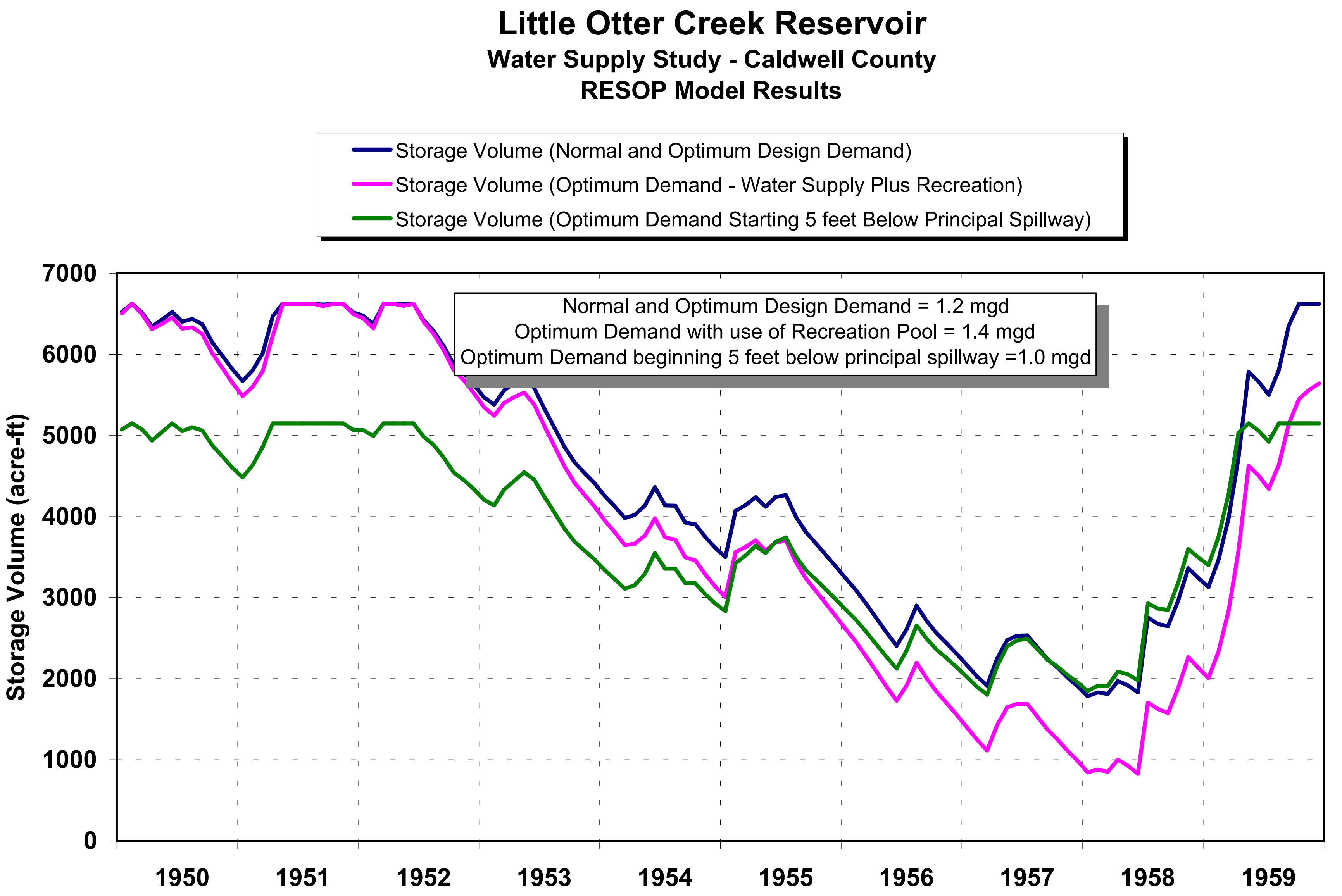

Little Otter Creek Reservoir
Water Supply Study - Caldwell County
RESOP Model Results
Storage Volume (Normal and Optimum Design Demand)
Storage Volume (Optimum Demand - Water Supply Plus Recreation)
Storage Volume (Optimum Demand Starting 5 feet Below Principal Spillway)
Normal and Optimum Design Demand = 1.2 mgd
Optimum Demand with use of Recreation Pool = 1.4 mgd
Optimum Demand beginning 5 feet below principal spillway =1.0 mgd
Storage Volume (acre-ft)
7000
6000
5000
4000
3000
2000
1000
0
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 27.3

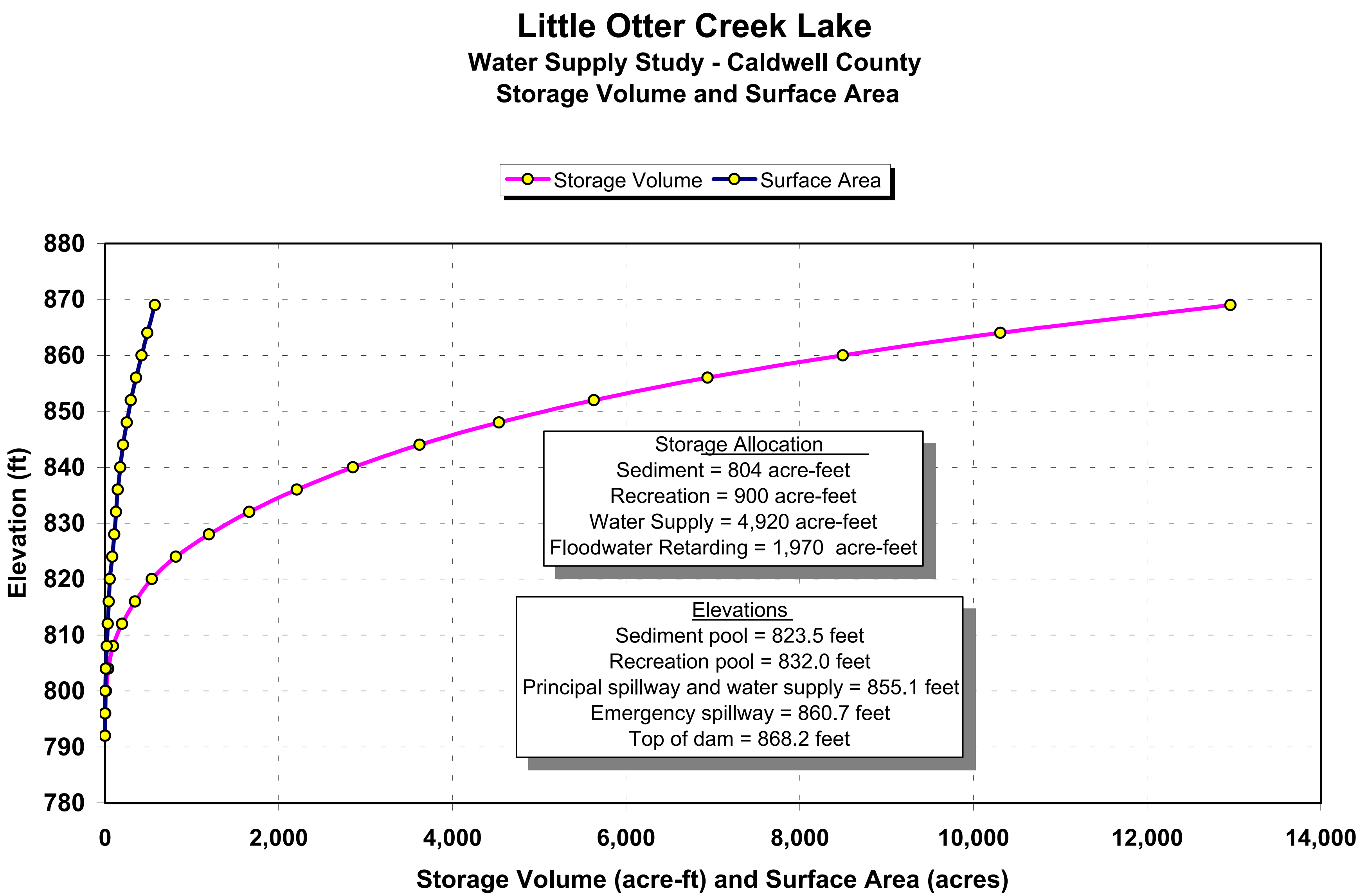

Little Otter Creek Lake
Water Supply Study - Caldwell County
Storage Volume and Surface Area
Storage Volume
Surface Area
Elevation (ft)
880
870
860
850
840
830
820
810
800
790
780
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
Storage Volume (acre-ft) and Surface Area (acres)
Storage Allocation
Sediment = 804 acre-feet
Recreation = 900 acre-feet
Water Supply = 4,920 acre-feet
Floodwater Retarding = 1,970 acre-feet
Elevations
Sediment pool = 823.5 feet
Recreation pool = 832.0 feet
Principal spillway and water supply = 855.1 feet
Emergency spillway = 860.7 feet
Top of dam = 868.2 feet

Figure 27.4

Marceline Reservoir System
Water Supply Study – Marceline, Missouri
Drought Assessment Analysis

I. Overview

Marceline City Reservoir (New) (figure 28.1) is located in southeast Linn County, Missouri, four miles southwest of Marceline. Marceline Reservoir is the primary source of water for the City of Marceline. North Lake (Old) is 1.5 miles northeast of Marceline is no longer used. An additional source of water supply, in an unexpected emergency, can be diverted from Mussel Fork Creek. The Marceline Reservoir serves a population of approximately 2,548 with an estimated water demand of 0.365 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

The City of Marceline draws water directly from the reservoir to the treatment facility. They also supply water for Chariton-Linn Public Water Supply District #3. Their old lake can supplement demand to Marceline Reservoir and provisions are in place to divert water from Mussel Fork Creek. Historical demand on the reservoir in 2000 was reported to be 0.448 million gallons per day. Figure 28.2 illustrates historical water demand on the Marceline Reservoir. Water Demand has been increasing at a rate of about 5.2 percent per year.

The older North Lake is used only if the water supply becomes critical. This North Lake drainage area is 271 Acres. The lake has approximately 80 acres surface area and the lake was not surveyed. Storage-area relationships were proportioned based on USGS 7.5-minute quadrangle and Marceline Lake. The lake was estimated to be 18 feet deep when full.

While pumping from Mussel Fork Creek was not considered part of this operation plan a frequency analysis was made to estimate the dependability of using the creek as a water supply. Mussel Fork Creek intake location is East of Marceline and has a drainage of 146.7 square miles. The watershed shape is long and narrow, like many of North Missouri streams. Downstream of this location, at drainage area 267 square miles, is a stream gauge site. Records were kept from October 1948 through September 1951 and again Oct 1962 through February 1990. For the 1950's, it was necessary to use the Locust Creek gauge. Gauge data was adjusted to the intake point by the drainage area ratio. A frequency analysis determined mean monthly discharges at the intake for the 100 year (1%), 50 year (2%), and 25 year (4%) chance of non-exceedance resulted in low flow values of 1 cubic feet per second or less for about half of the months. The 7-day duration 10-year frequency low flow, which is needed to meet in-stream flow requirements, is near zero. Analysis of the data indicates that flow in Mussel Fork Creek at the intake location would be so low during drought periods that withdraw would probably not be possible.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Marceline (New) Reservoir. The Old Marceline Reservoir is available in case of water shortages, as is diverting water from Mussel Fork Creek. These potential sources were not considered within the context of this model. The RESOP model assumes that ‘Normal’ demand for Marceline is 0.448 million gallons per day and that ‘Optimum’ yield from the lake is 0.412 million gallons per day. Figure 28.3.a illustrates these relationships. Figure 28.3.b illustrates an estimate of the old reservoir’s ability to provide water during extended droughts. Only the optimum demand was estimated and displayed. Optimum demand from the old reservoir is 60,000 gallons per day.

II. Drought Assessment Summary

The Marceline Reservoir (New) is capable of meetings Marceline's water demand of 0.448 million gallons per day, however the reservoir volume would be dangerously at risk of not meeting the demand. Water from the old lake would need to be added to the system in 1957 and 1958 to meet demand. The 2000 demand on the reservoir was approximately 448,000 gallons per day, and when this demand value is applied to the reservoir during the drought of record in the 1950's, water in the reservoir be drawn down so low it may not be useable.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. Detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Marceline City Lake (New) Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on May 19, 2003. Surface area of the lake and associated storage volume capacity is illustrated in figure 28.4. North Lake (Old) was not surveyed and associated physical data was estimated based on local topographic features.

Marceline Reservoirs Lake Physical Data

Marceline City Lake (New)				***North Lake (Old) (Not Surveyed)***		
Elevation (feet)	Area (acres)	Volume (acre-feet)		Assumed Elevation (feet)	Assumed Area (acres)	Estimated Volume (acre-feet)
729	0	0		100.0	0.0	0.0
730	5	3		100.5	2	0.6
732	13	20		101.6	6	4.8
734	21	55		102.7	9	12.7
736	31	106		103.8	13	24.7
738	41	178		104.9	17	41.4
740	53	272		106.0	22	63.3
742	64	389		107.1	27	90.4
744	75	528		108.2	32	122.7
746	85	688		109.3	36	159.8
748	97	870		110.4	41	202.1
750	110	1,080		111.5	47	250.1
752	122	1,310		112.6	52	304.0
754	135	1,570		113.7	57	363.6
754.5	139	1,630		114.0	59	379.5
756	151	1,850		114.8	64	400.0
756.9	160	1,990		115.3	68	462.5
760	189	2,531		117.0	80	588.1
Spillway Elevation = 756.9 feet Lake Conditions May 19, 2003 Elevation = 754.5 feet				Estimated Spillway Elevation = 115.3 feet		

[LIMITS]

Marceline City Lake (New)

Maximum Storage……………………………………………………………………1990 acre-feet.
Minimum Storage……………………………………………………………………..200 acre-feet.

Drainage Basin Size…………………………………………………………..3.73 square miles.

Initial storage volume was equated to the reservoir volume at maximum capacity.

North Lake (Old)

Maximum Storage…………………………………………………………………...462 acre-feet.
Minimum Storage……………………………………………………………………….60 acre-feet.

Drainage Basin Size……………………………………………………………………….271 acres.

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Marceline City Lake (New) and also North Reservoir (Old) Lake is estimated to be approximately 3.0 inches per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoirs are bound by earthen dams composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation values for the drought of record were obtained from Brookfield gauge.

Average precipitation in Brookfield was 38.9 inches between 1950 and 2000. The most severe drought occurred between 1953 and 1957 with annual precipitation values of 27.56 inches, 38.71 inches, 34.05 inches, 23.36 inches, and 48.20 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Locust Creek stream gauge at Linneus. The drainage area monitored by this stream gauge covers approximately 550 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Brookfield, individual storm events were considered. Antecedent soil moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service’s (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from both Marceline Reservoirs due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or

Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

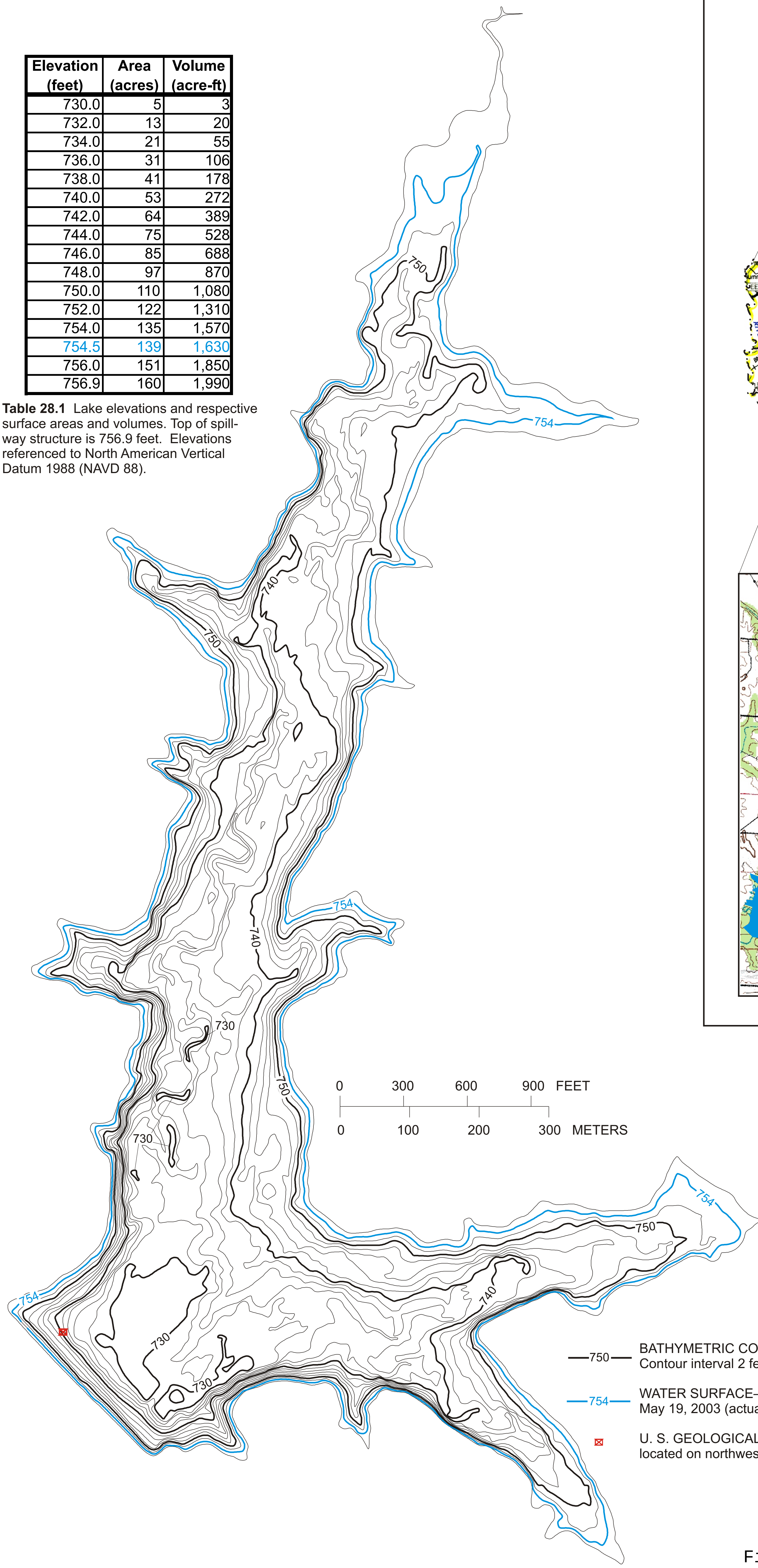
Water demand was obtained from records reported by the city to Missouri Department of Natural Resources “Major Water Users Data Base” (figure 28.2). Demand for this analysis was 0.448 million gallons per day. Marceline water demand has been increasing at a rate of about five-percent each year between 1988 and 2001.

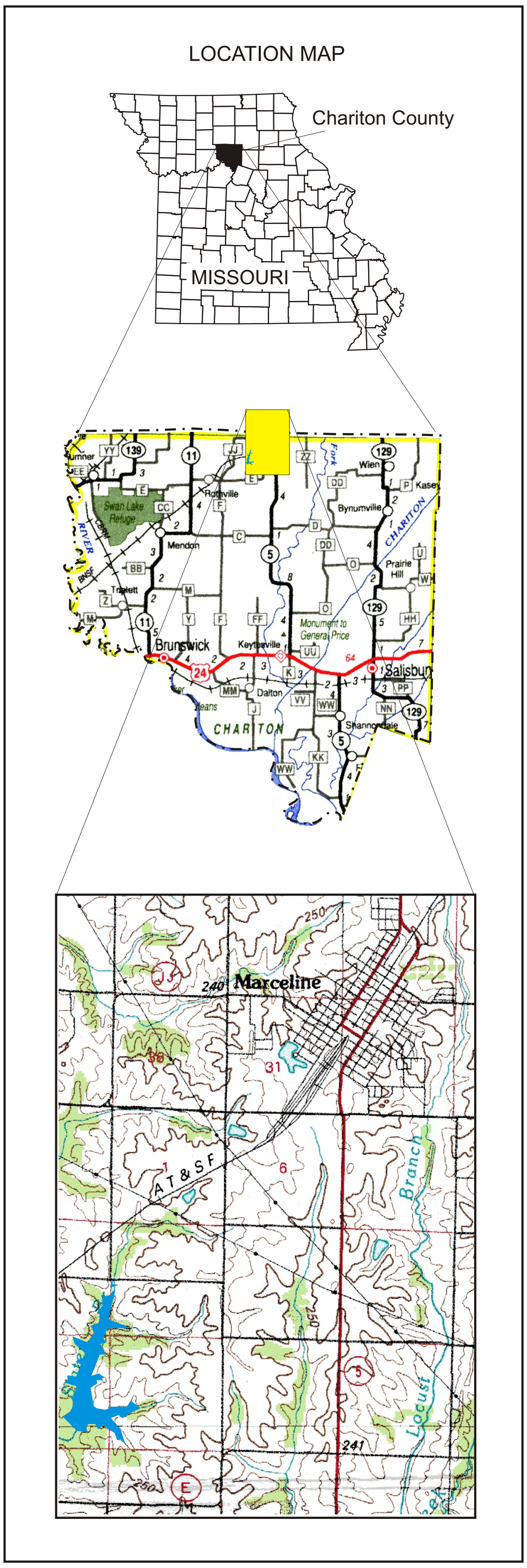
North Lake (Old) is not currently being used for water supply and only an optimized analysis was made.

MARCELINE LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
730.0	5	3
732.0	13	20
734.0	21	55
736.0	31	106
738.0	41	178
740.0	53	272
742.0	64	389
744.0	75	528
746.0	85	688
748.0	97	870
750.0	110	1,080
752.0	122	1,310
754.0	135	1,570
754.5	139	1,630
756.0	151	1,850
756.9	160	1,990

Table 28.1 Lake elevations and respective surface areas and volumes. Top of spillway structure is 756.9 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).





EXPLANATION

750 BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

754 WATER SURFACE—Shows approximate elevation of water surface, May 19, 2003 (actual is 754.5 feet, table 21).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on northwest side of intake tower. Elevation 764.1 feet.

Figure 28.1

Figure 28.1 Bathymetric map and table of areas/volumes of the Marceline Lake (New) near Marceline, Missouri.

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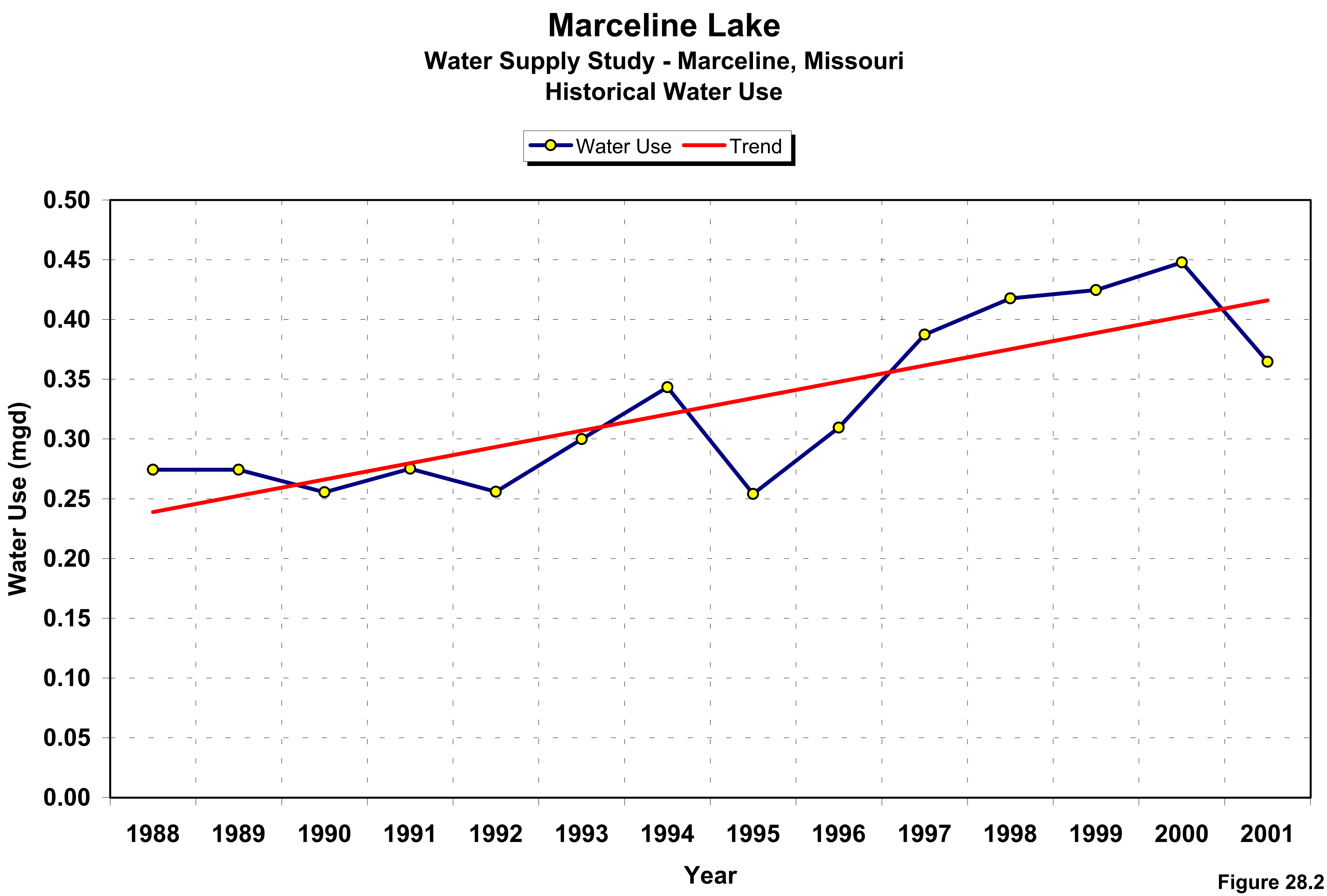

Marceline Lake
Water Supply Study - Marceline, Missouri
Historical Water Use
Water Use
Trend
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Water Use (mgd)
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 28.2

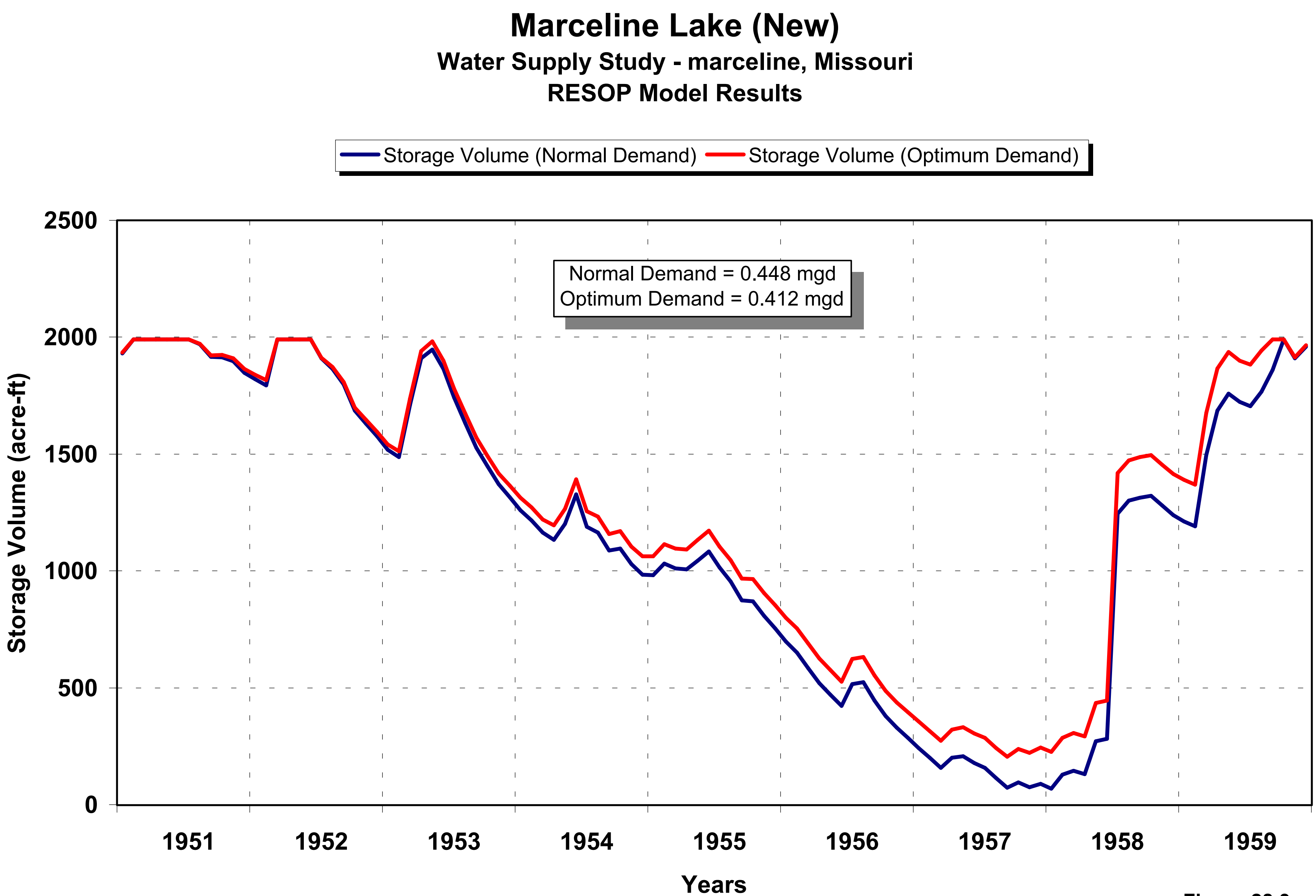

Marceline Lake (New)
Water Supply Study - marceline, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 0.448 mgd
Optimum Demand = 0.412 mgd
2500
2000
1500
1000
500
0
Storage Volume (acre-ft)
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 28.3.a

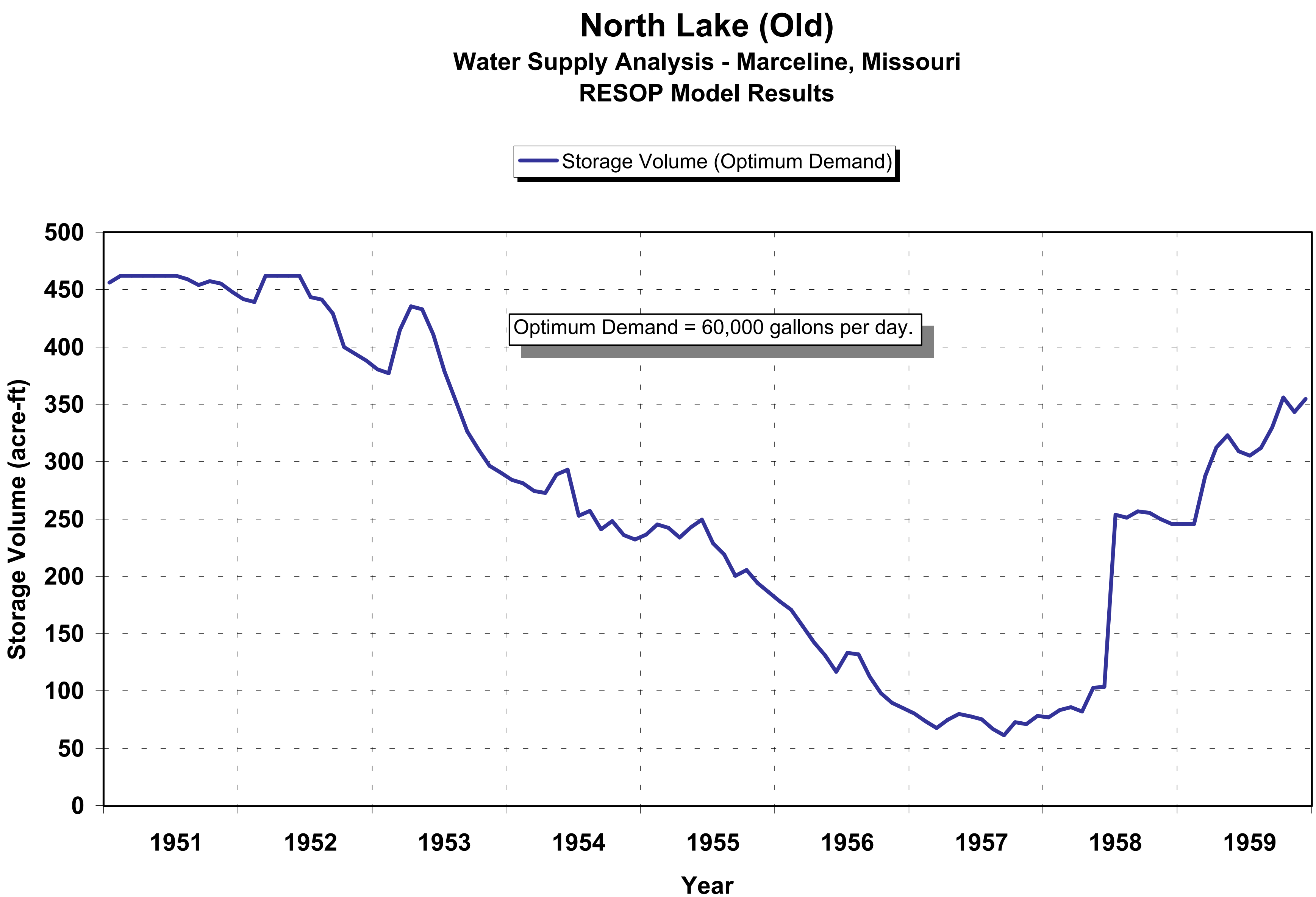

North Lake (Old)
Water Supply Analysis - Marceline, Missouri
RESOP Model Results
Storage Volume (Optimum Demand)
Optimum Demand = 60,000 gallons per day.
Storage Volume (acre-ft)
500
450
400
350
300
250
200
150
100
50
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 28.3.b

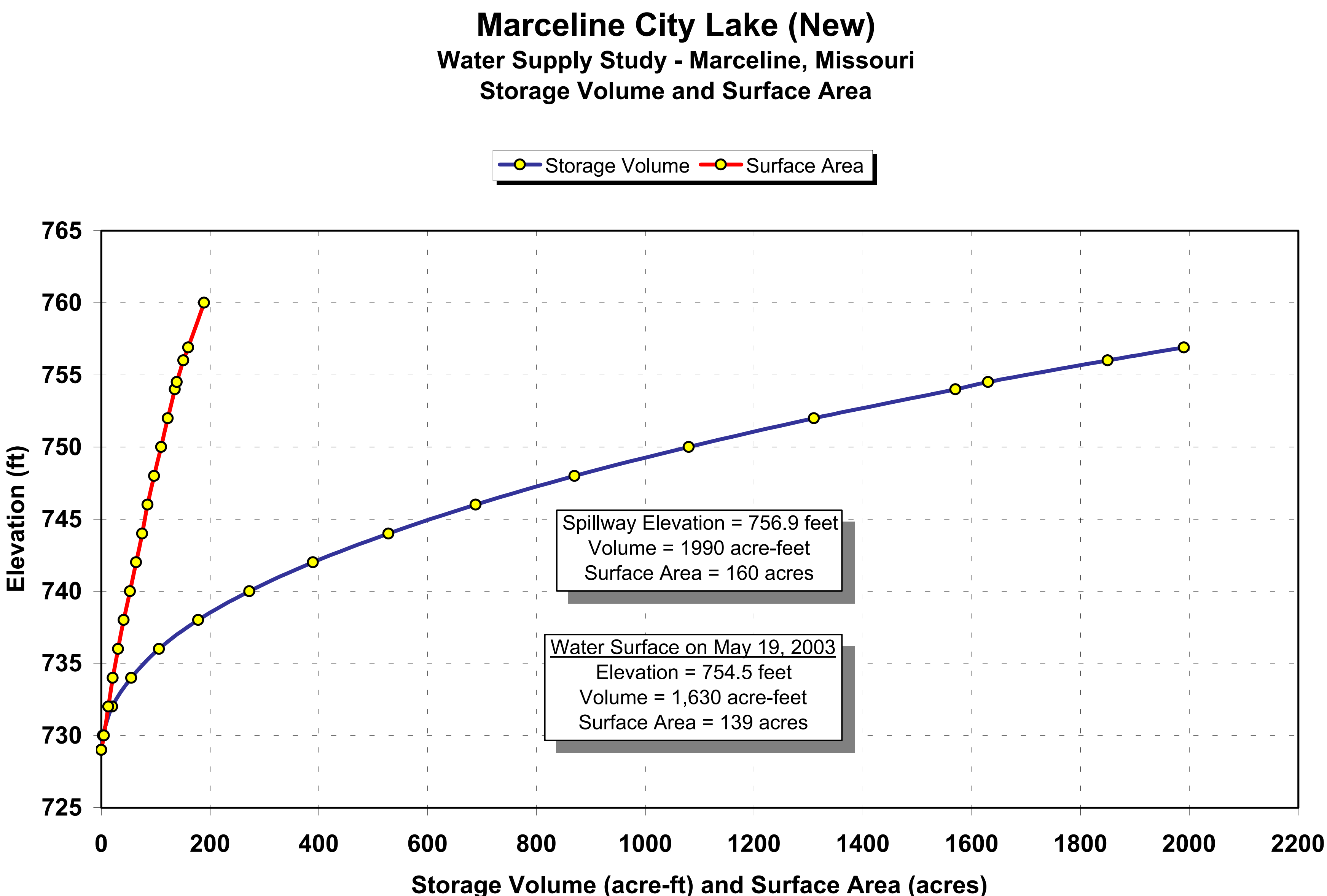

Marceline City Lake (New)
Water Supply Study - Marceline, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
765
760
755
750
745
740
735
730
725
Elevation (ft)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 756.9 feet
Volume = 1990 acre-feet
Surface Area = 160 acres
Water Surface on May 19, 2003
Elevation = 754.5 feet
Volume = 1,630 acre-feet
Surface Area = 139 acres

Figure 28.4.a

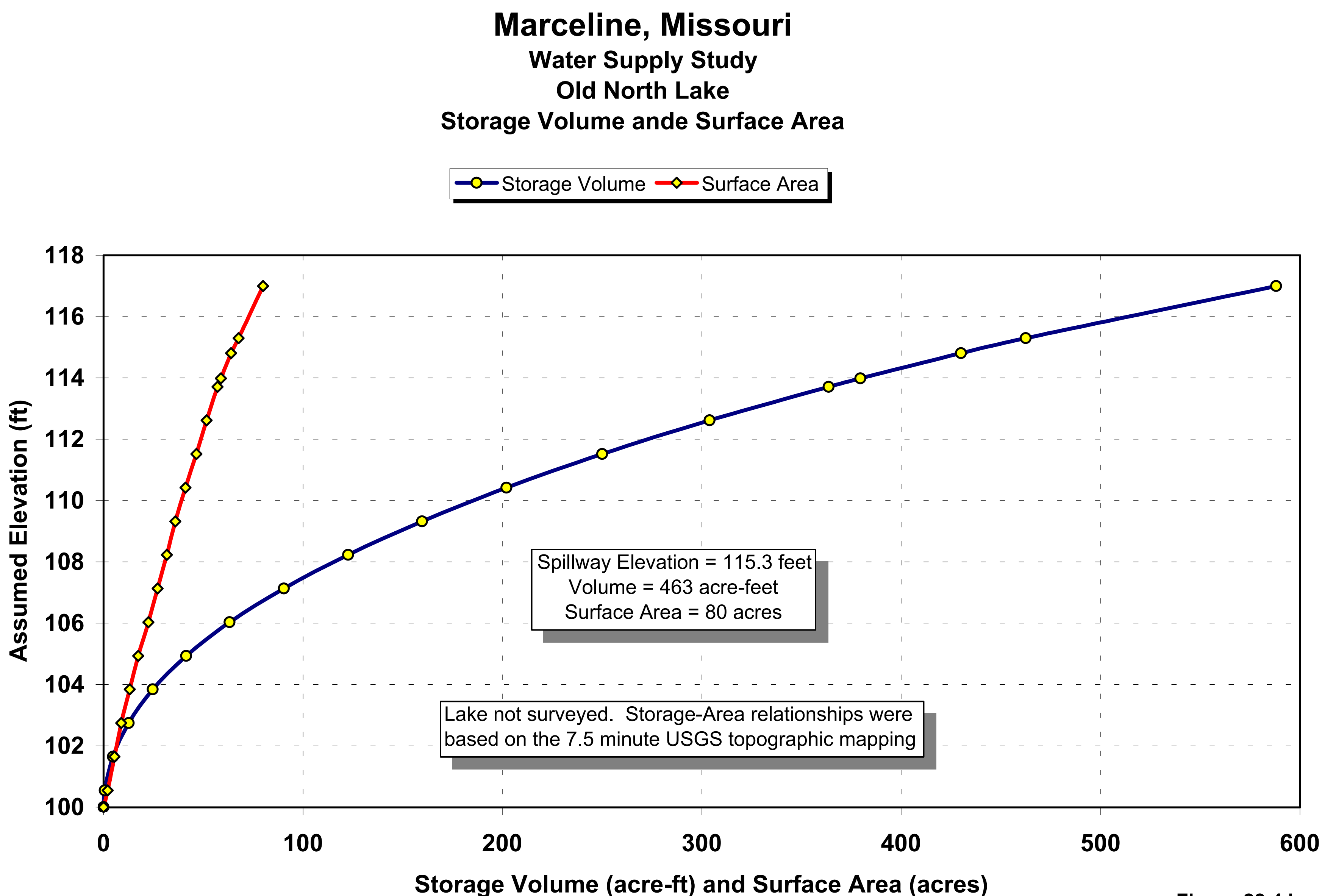

Marceline, Missouri
Water Supply Study
Old North Lake
Storage Volume ande Surface Area
Storage Volume
Surface Area
118
116
114
112
110
108
106
104
102
100
Assumed Elevation (ft)
0
100
200
300
400
500
600
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 115.3 feet
Volume = 463 acre-feet
Surface Area = 80 acres
Lake not surveyed. Storage-Area relationships were
based on the 7.5 minute USGS topographic mapping

Figure 28.4.b

Maysville Lakes System
Water Supply Study – Maysville, Missouri
Drought Assessment Analysis

I. Overview

Maysville three reservoirs (figures 29.1.a, 29.1.b and 29.1.c) are located near the center of the DeKalb County. They have three lakes available for use as water supply. They are South, West and Willowbrook Lakes. Willowbrook Lake is the new lake from which the city began using water in 1997. This is the only lake they are currently using for water supply. The other two are kept in reserve for emergencies. Missouri Department of Conservation manages Willowbrook Lake for fish and wildlife. The Maysville Reservoir System serves a population of approximately 1,100 with an estimated water demand of 0.139 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

The South Lake is located approximately one half mile south of Maysville, West Lake is about one half mile west of the city and Willowbrook Lake is about 1 mile southwest of the city. The lakes are owned by the city and supply water to Maysville. The drainage area for each lake is South Lake 0.22 square miles, West Lake 3.21 square miles and Willowbrook has 5.84 square miles.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Willow Brook Lake Reservoir. The model assumes that ‘Normal’ demand for Willow Brook Lake is 0.14 million gallons per day and that ‘Optimum’ yield from the lake is 0.31 million gallons per day. Figure 29.3.a illustrates these relationships. Optimum yield for West Lake and South Lake was 0.12 and 0.02 million gallons respectively.

II. Drought Assessment Summary

Willowbrook Reservoir is capable of meeting Maysville’s demand for water during a severe drought, such as the one in the 1950’s, without additional sources of water. The 2004 demand on the reservoir system was approximately 0.123 million gallons per day. For the period 1994 through 1996 Maysville reported using 0.139 million gallons per day. This analysis used 0.14 million gallons per day. When this demand value is applied to the reservoir during the drought of record in the 1950’s, Willowbrook Reservoir has a reserve of 400 acre-feet of water. The estimated optimum yield from Willowbrook Reservoir is 0.31 million gallons per day (figure 29.3.a).

West Lake or South Lake is not capable of satisfying domestic water supply during an extended drought. Optimum yield from West Lake is 0.12 million gallons per day and South Lake would yield 0.02 million gallons per day (figures 29.3.b and 29.3.c).

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving

these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from bathymetric surveys of Willow Brook Lake, South Lake, and West Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on March 21 through 25, 2000. Surface area of the lake and associated storage volume capacities are illustrated in figure 29.4.a, 29.4.b and 29.4.c..

Willow Brook Lake Physical Data

Willow Brook Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	
886.0	0.10	0.04	
888.0	1.8	1.40	
890.0	5.9	6.00	
892.0	10.7	25.3	
894.0	18.8	53.6	
896.0	33.2	106.2	
898.0	46.5	186.1	
900.0	60.1	291.7	
902.0	73.0	424.9	
904.0	90.4	587.4	
906.0	106.9	784.4	Principal spillway (From as built plans)
908.0	126.0	1,017.9	
909.6	139.4	1,229.6	Lake conditions on July 25, 2000
910.0	142.9	1,286.2	
912.0	155.6	1,584.4	
914.0	170.0	1,909.8	
916.0	186.7	2,266.0	
918.0	206.8	2,658.6	Emergency spillway

South Reservoir				***West Reservoir***		
Elevation (feet)	Area (acres)	Volume (acre-feet)		Elevation (feet)	Area (acres)	Volume (acre-feet)
884.0	1.2	0.8		886.0	0.1	0.0
886.0	2.1	4.0		888.0	2.4	2.0
888.0	3.0	9.0		890.0	7.2	11.0
890.0	4.1	16.3		892.0	13.7	31.8
892.0	5.6	25.9		894.0	22.2	67.0
894.0	6.5	38.0		896.0	30.9	122
896.0	7.8	52.1		898.0	37.6	191
898.0	8.7	69.0		899.3	40.9	242
898.6	8.9	75.0		899.5	41.7	250
Lake Conditions March 21, 2006 = 898.0 feet Principal Spillway Elevation = 898.6 feet				Lake Conditions March 21, 2006 = 899.5 feet Principal Spillway Elevation = 899.3 feet		

[LIMITS]

Willow Brook Lake
Maximum storage ....785 acre-feet
Minimum storage ....50 acre-feet
Drainage basin size .... 5.84 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

West Lake
Maximum storage ....250 acre-feet
Minimum storage ....20 acre-feet
Drainage basin size .... 3.21 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

South Lake
Maximum storage ....75 acre-feet
Minimum storage ....15 acre-feet
Drainage basin size .... 0.22 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Willow Brook Lake is approximately 1.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

Seepage from West Lake is approximately 0.5 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

Seepage from South Lake is approximately 0.75 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Average precipitation in Maysville was 36.2 inches between 1950 and 2000. Precipitation values for the drought of record were obtained from Amity, Missouri (approximately 4 miles west-southwest of Maysville). The most severe drought occurred between 1953 and 1957 with annual precipitation values in Amity of 25.71 inches, 37.58 inches, 33.93 inches, 20.76 inches, and 31.52 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Jenkins Branch stream gauge (a tributary of the Platte River), located approximately 20 miles

southwest of Maysville. The drainage area monitored by this stream gauge covers approximately 2.72 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Maysville, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from each of Maysville three reservoirs due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

Water demand was obtained from records reported by the city records to Missouri Department of Natural Resources "Major Water Users Data Base". Their water use has been reasonably steady for the period of 1989 through 2004. In 1994, 1995 and 1996 Maysville reported using 0.14 million gallons per day. For this evaluation, 0.14 million gallons per day was assumed.

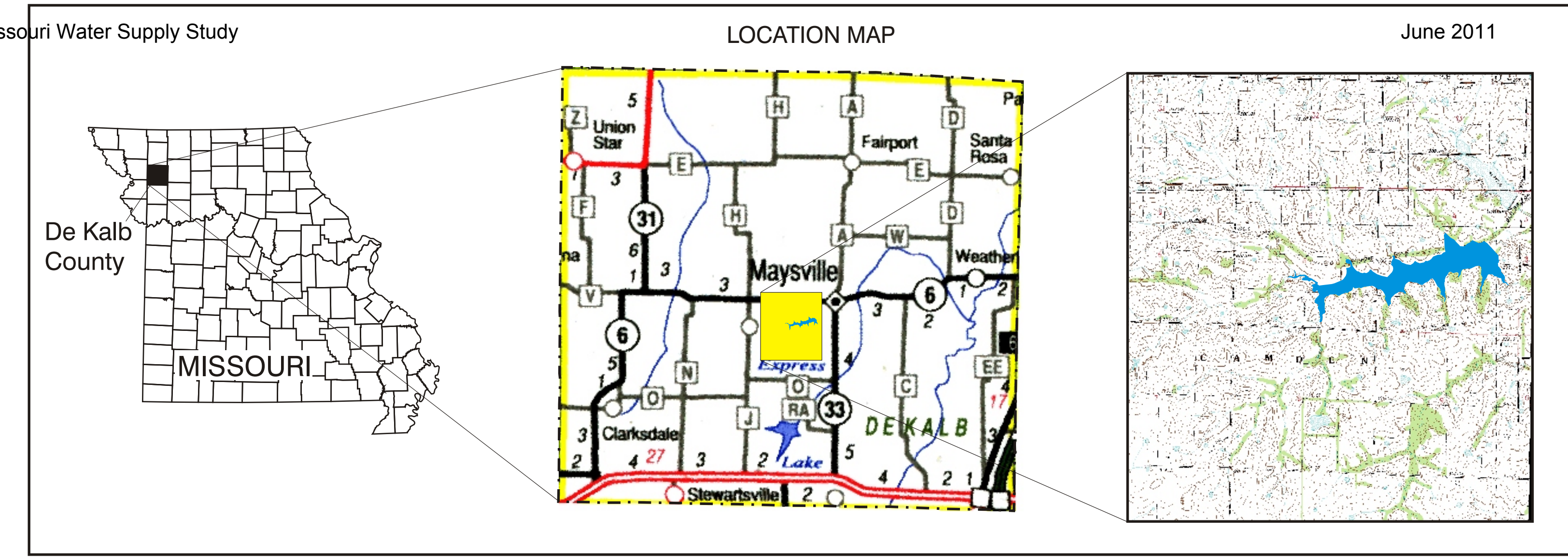
Missouri Department of Natural Resources
Water Resources Center

Elevation (feet)	Area (acres)	Volume (acre-ft)
886.0	0.1	0.04
888.0	1.8	1.4
890.0	5.9	9.0
892.0	10.7	25.3
894.0	18.8	53.6
896.0	33.2	106.2
898.0	46.5	186.1
900.0	60.1	291.7
902.0	73.0	424.9
904.0	90.4	587.4
906.0	106.9	784.4
908.0	126.0	1,017.9
909.6	139.4	1,229.6
910.0	142.9	1,286.2
912.0	155.6	1,584.4
914.0	170.0	1,909.8
916.0	186.7	2,266.0
918.0	206.8	2,658.6

Lake elevations and respective areas and volumes. Emergency spillway elevation is approximately 918 ft. Datum is sea level.

MAYSVILLE LAKE

Willowbrook Lake



EXPLANATION

— 900 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

— 910 — WATER SURFACE—Shows approximate elevation of water surface, July 25, 2000 (actual is 909.6 feet, table 9). Datum is sea level.

U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west edge of spillway. Elevation 915.0 feet. Datum is sea level.

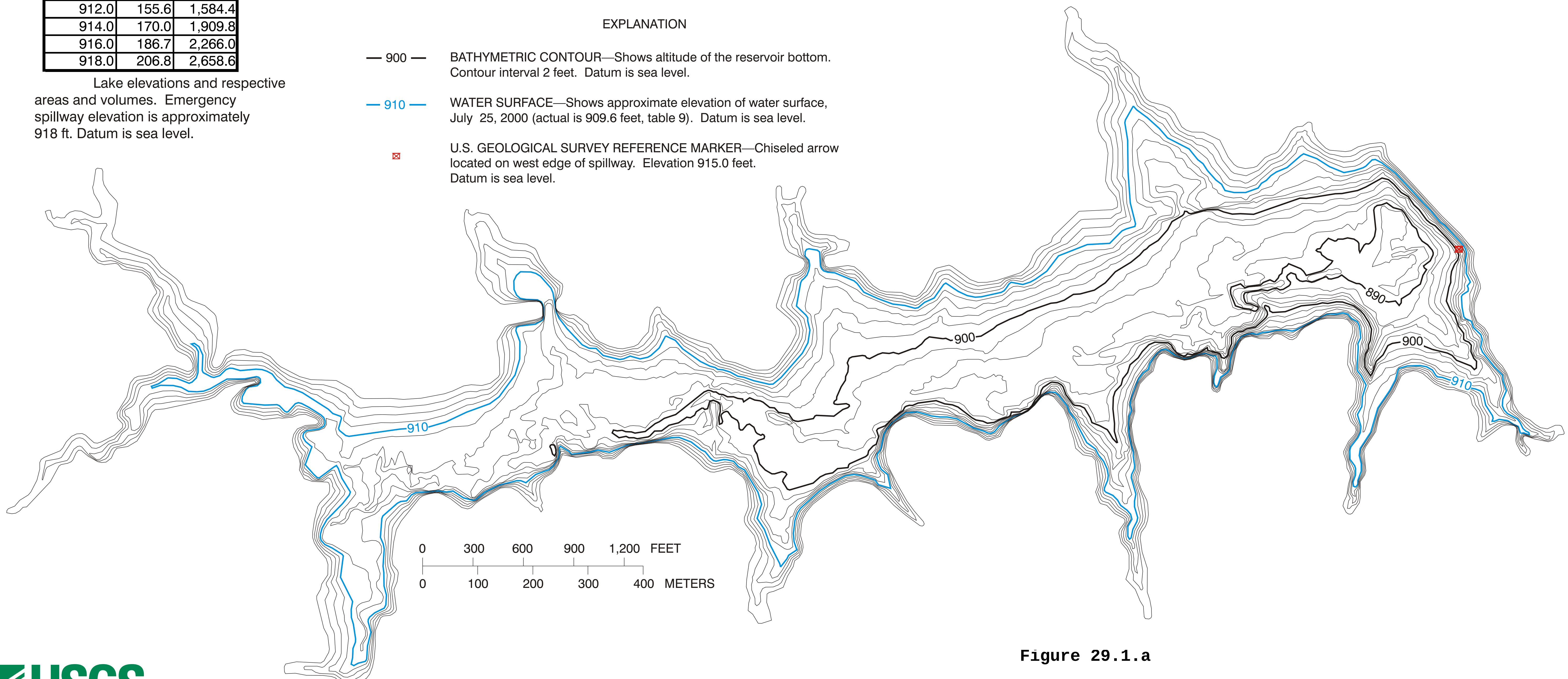


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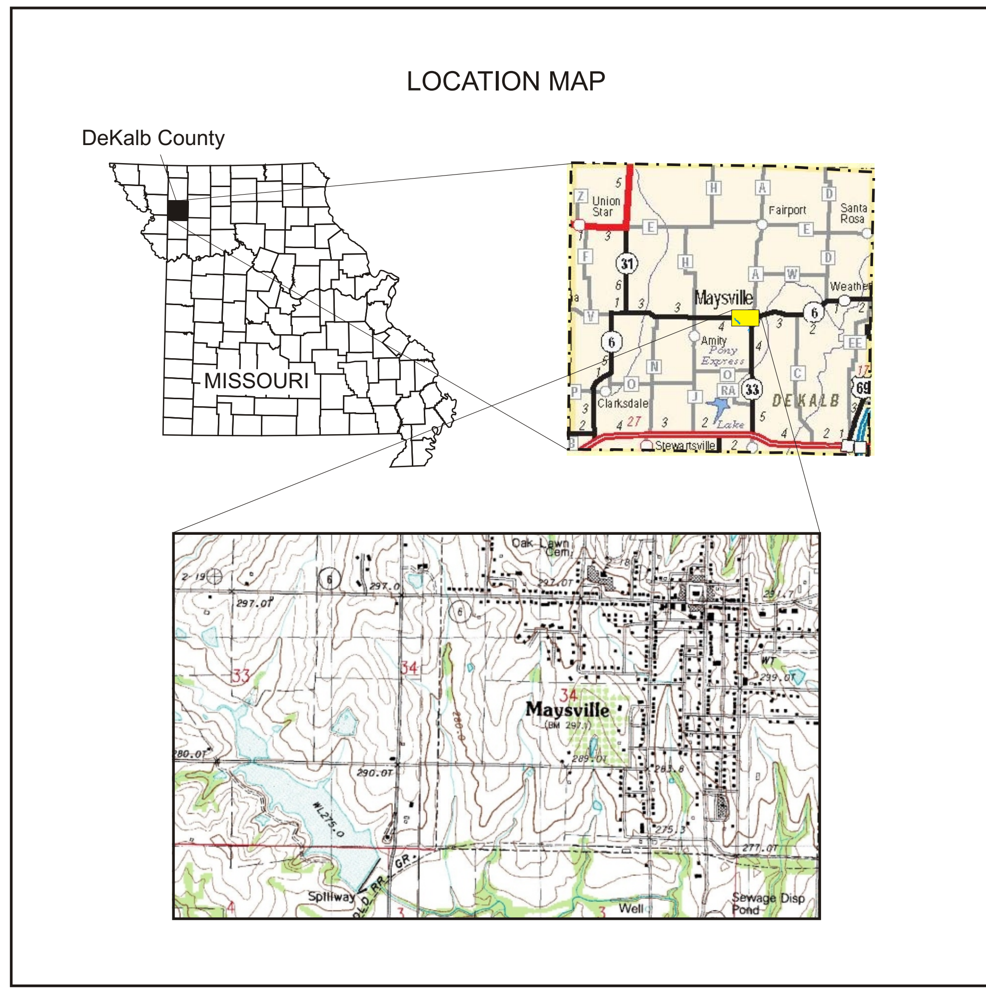
Figure 29.1.a

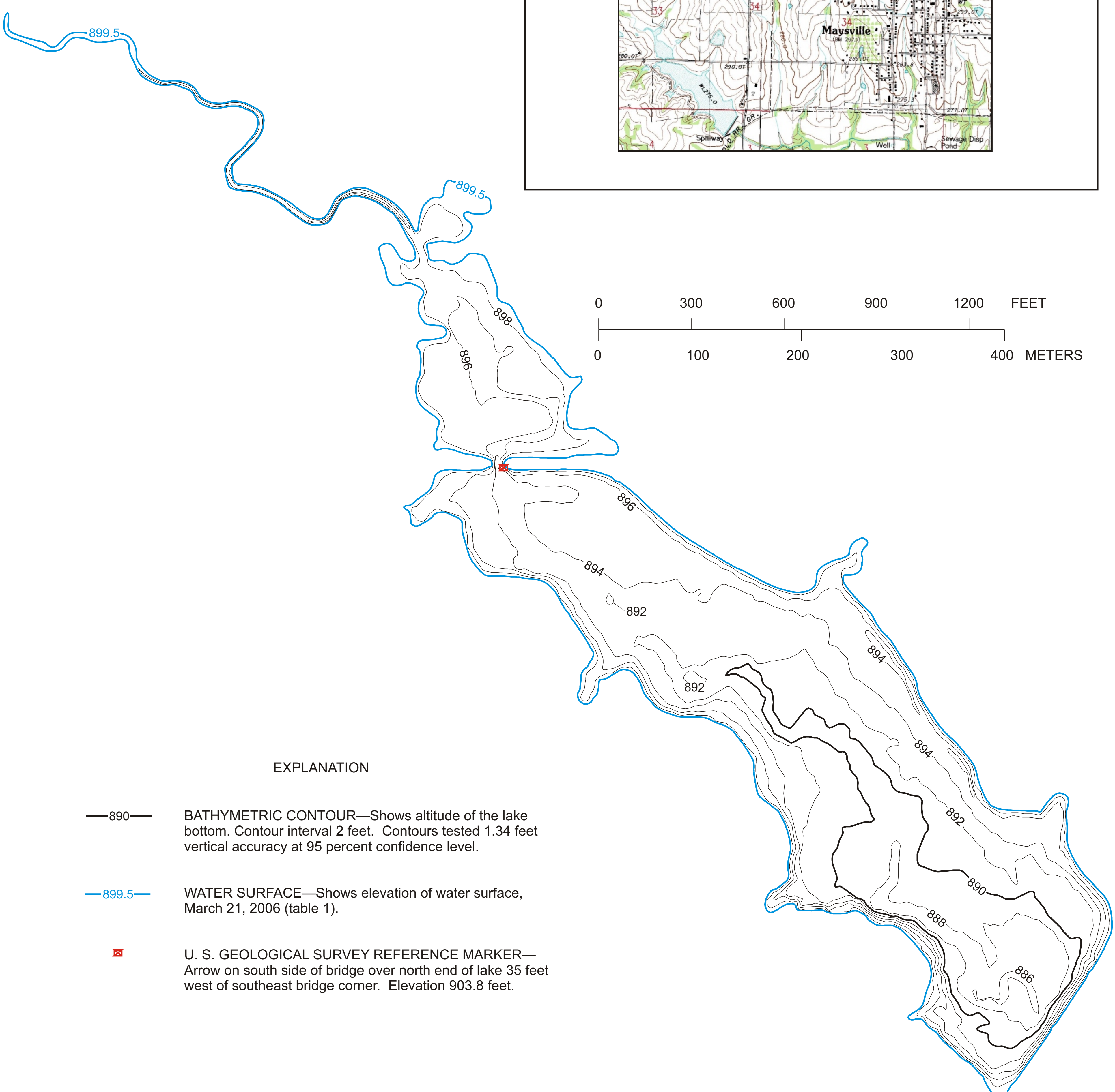
Bathymetric map and table of areas/volumes of the Maysville Lake #3 Intake near Maysville, Missouri.

MAYSVILLE WEST LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
886.0	0.1	-
888.0	2.4	2.0
890.0	7.2	11.0
892.0	13.7	31.8
894.0	22.2	67.0
896.0	30.9	122
898.0	37.6	191
899.3	40.9	242
899.5	41.7	250

Table 29.1.b Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 899.3 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.01 feet vertical accuracy at 95 percent confidence level.





EXPLANATION

—890— BATHYMETRIC CONTOUR—Shows altitude of the lake bottom. Contour interval 2 feet. Contours tested 1.34 feet vertical accuracy at 95 percent confidence level.

—899.5— WATER SURFACE—Shows elevation of water surface, March 21, 2006 (table 1).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Arrow on south side of bridge over north end of lake 35 feet west of southeast bridge corner. Elevation 903.8 feet.

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Figure 29.1.b

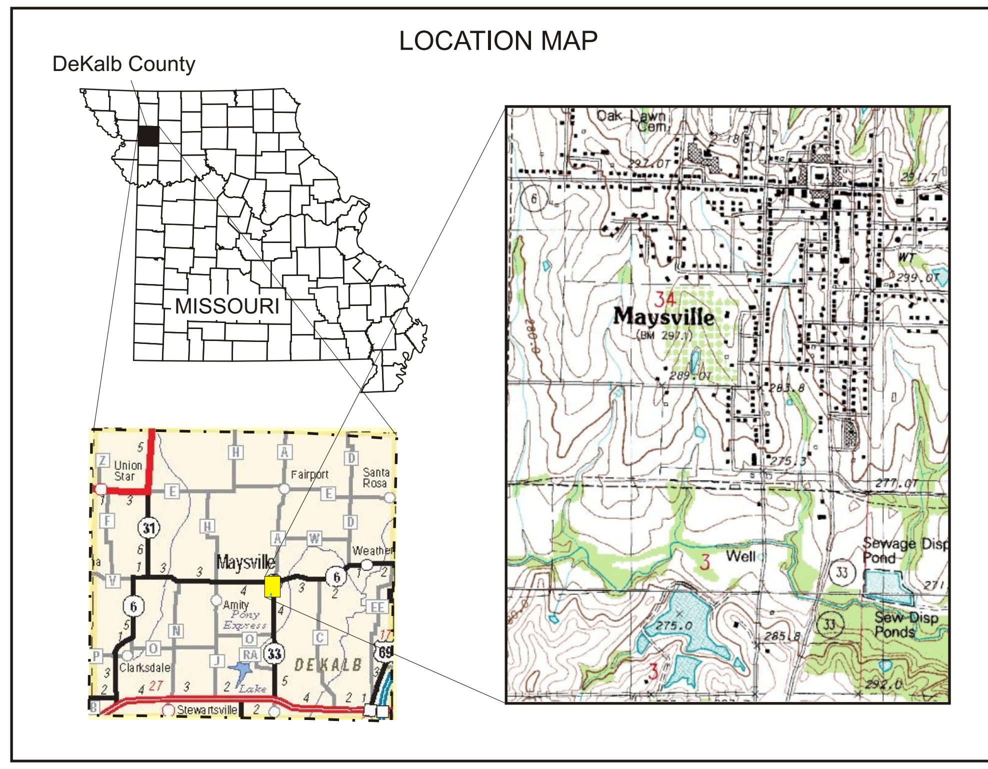
In cooperation with Missouri Department of Natural Resources

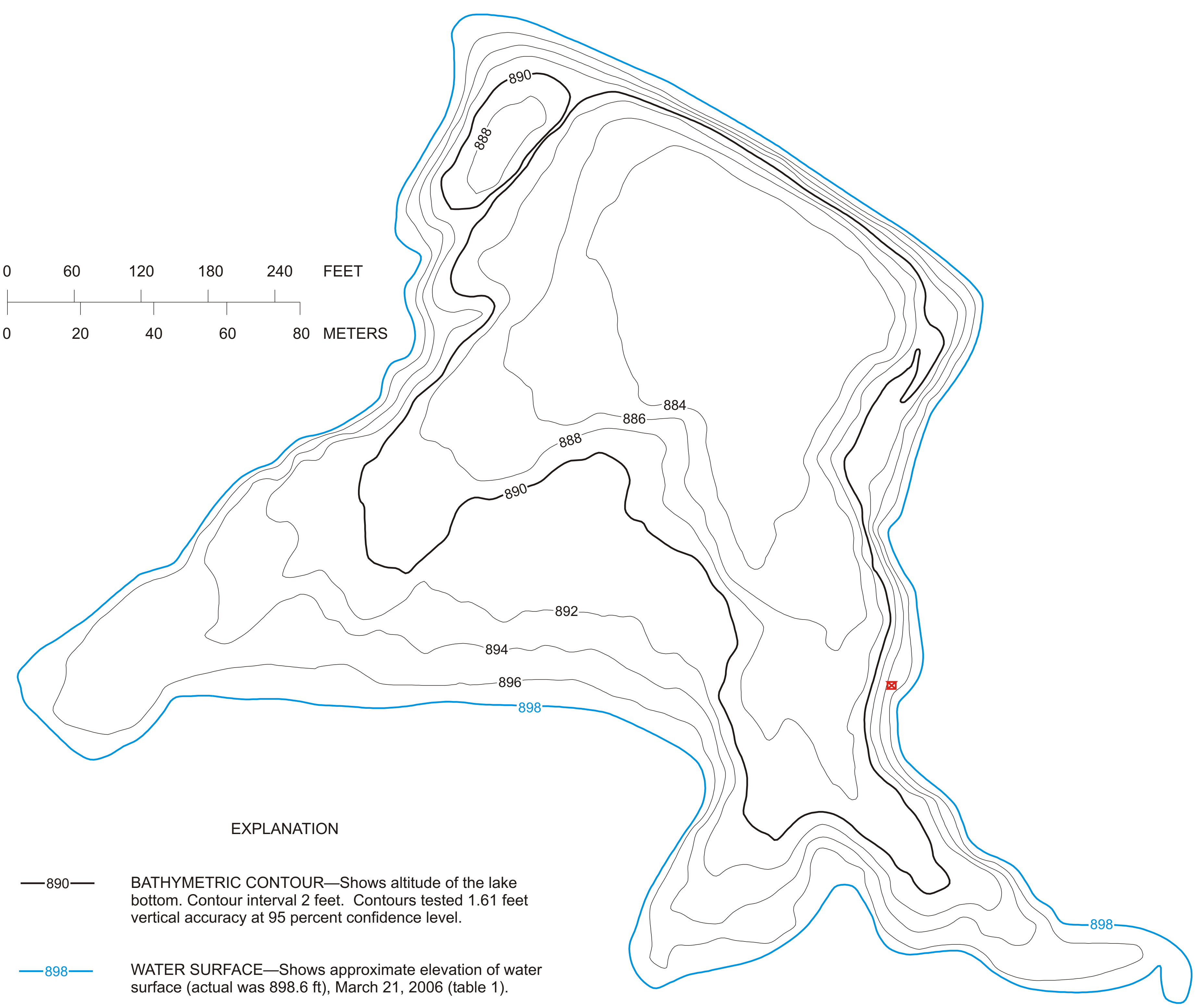
Figure 29.1.b Bathymetric map and table of areas/volumes of the Maysville West Lake near Maysville, Missouri.

MAYSVILLE SOUTH LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
884.0	1.2	0.8
886.0	2.1	4.0
888.0	3.0	9.0
890.0	4.1	16.3
892.0	5.6	25.9
894.0	6.5	38.0
896.0	7.8	52.1
898.0	8.7	69.0
898.6	8.9	74.6

Table 29.1.c Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 898.6 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.08 feet vertical accuracy at 95 percent confidence level.





EXPLANATION

—890— BATHYMETRIC CONTOUR—Shows altitude of the lake bottom. Contour interval 2 feet. Contours tested 1.61 feet vertical accuracy at 95 percent confidence level.

—898— WATER SURFACE—Shows approximate elevation of water surface (actual was 898.6 ft), March 21, 2006 (table 1).

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Top of 3/8 inch lag bolt in north side of tree stump near boat ramp. Elevation 899.3 feet.

USGS
science for a changing world

Figure 29.1.c

In cooperation with Missouri Department of Natural Resources

Figure 29.1.c Bathymetric map and table of areas/volumes of the Maysville South Lake near Maysville, Missouri.

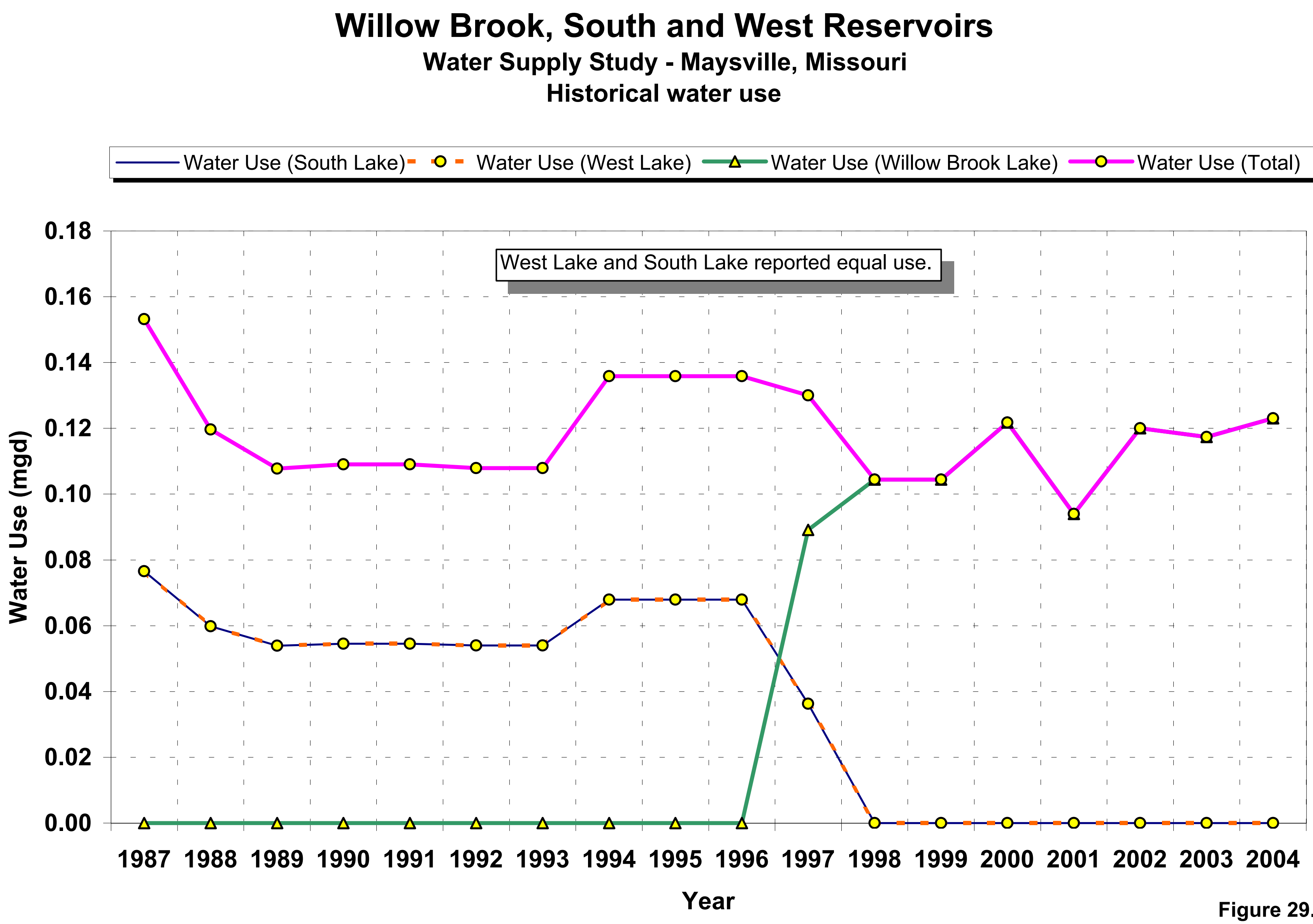

Willow Brook, South and West Reservoirs
Water Supply Study - Maysville, Missouri
Historical water use
Water Use (South Lake)
Water Use (West Lake)
Water Use (Willow Brook Lake)
Water Use (Total)
West Lake and South Lake reported equal use.
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Water Use (mgd)
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Year

Figure 29.2

Willow Brook Lake

Water Supply Study - Maysville, Missouri
RESOP Model Results

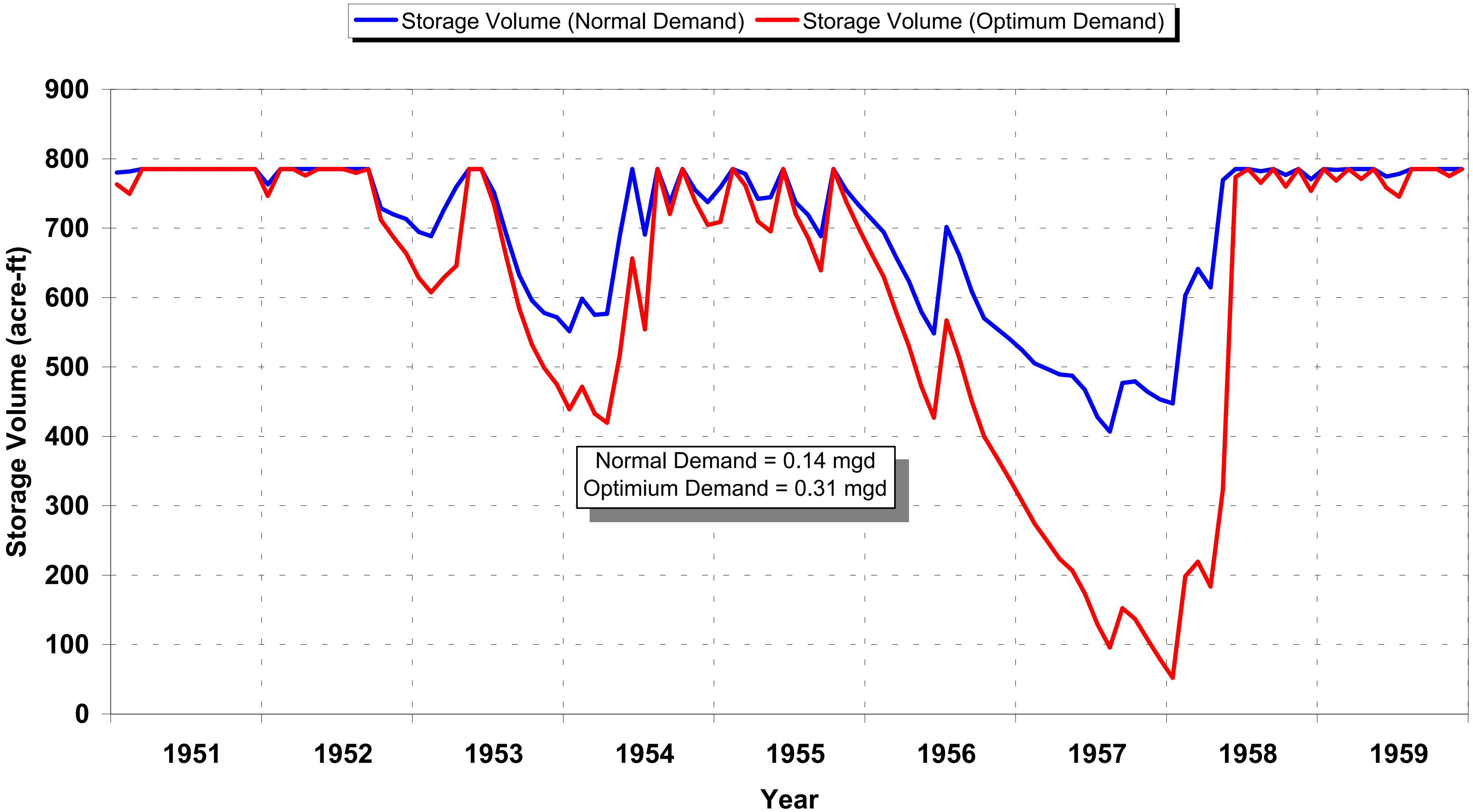


Figure 29.3.a

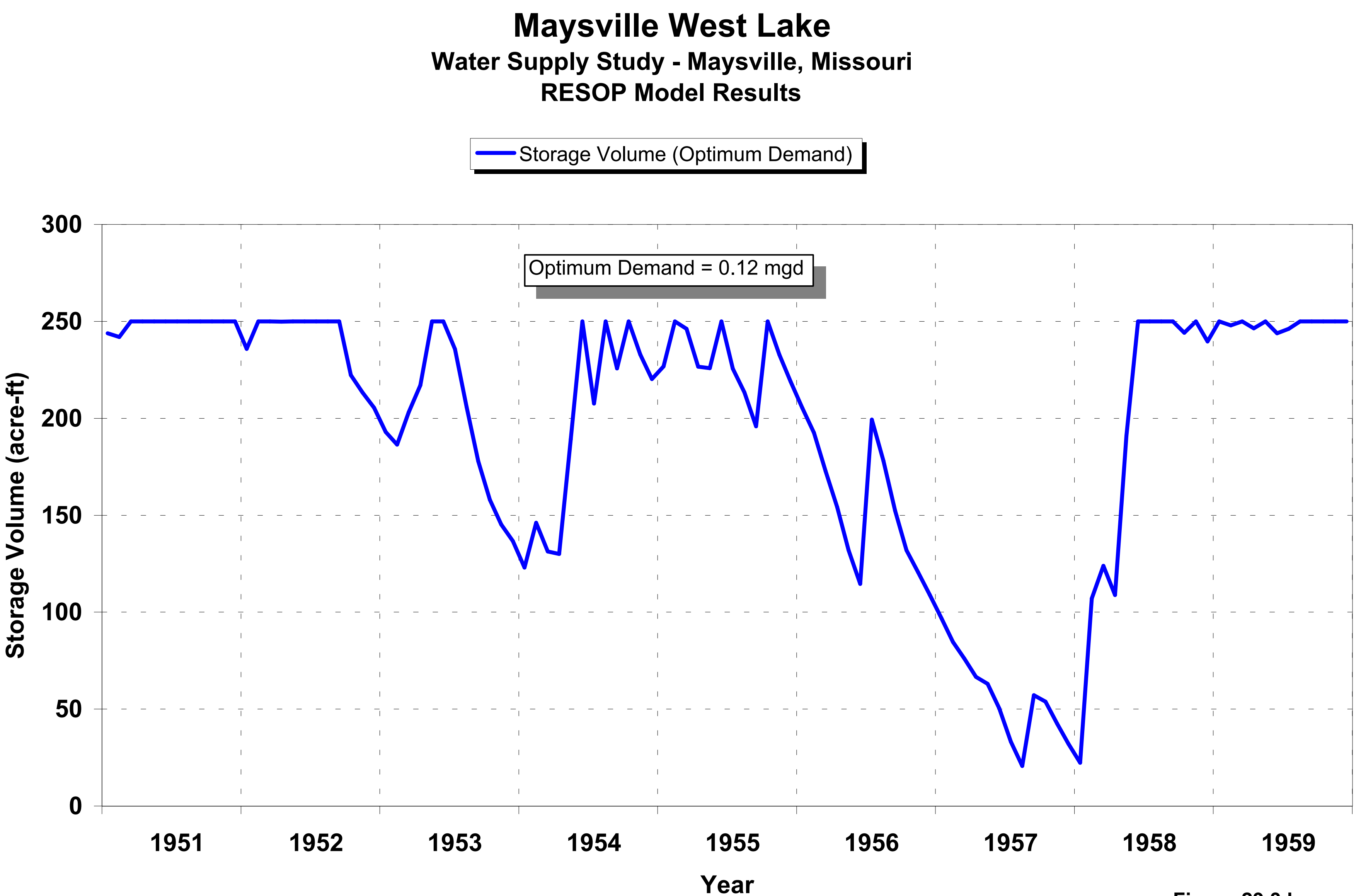

Maysville West Lake
Water Supply Study - Maysville, Missouri
RESOP Model Results
Storage Volume (Optimum Demand)
Optimum Demand = 0.12 mgd
300
250
200
150
100
50
0
Storage Volume (acre-ft)
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 29.3.b

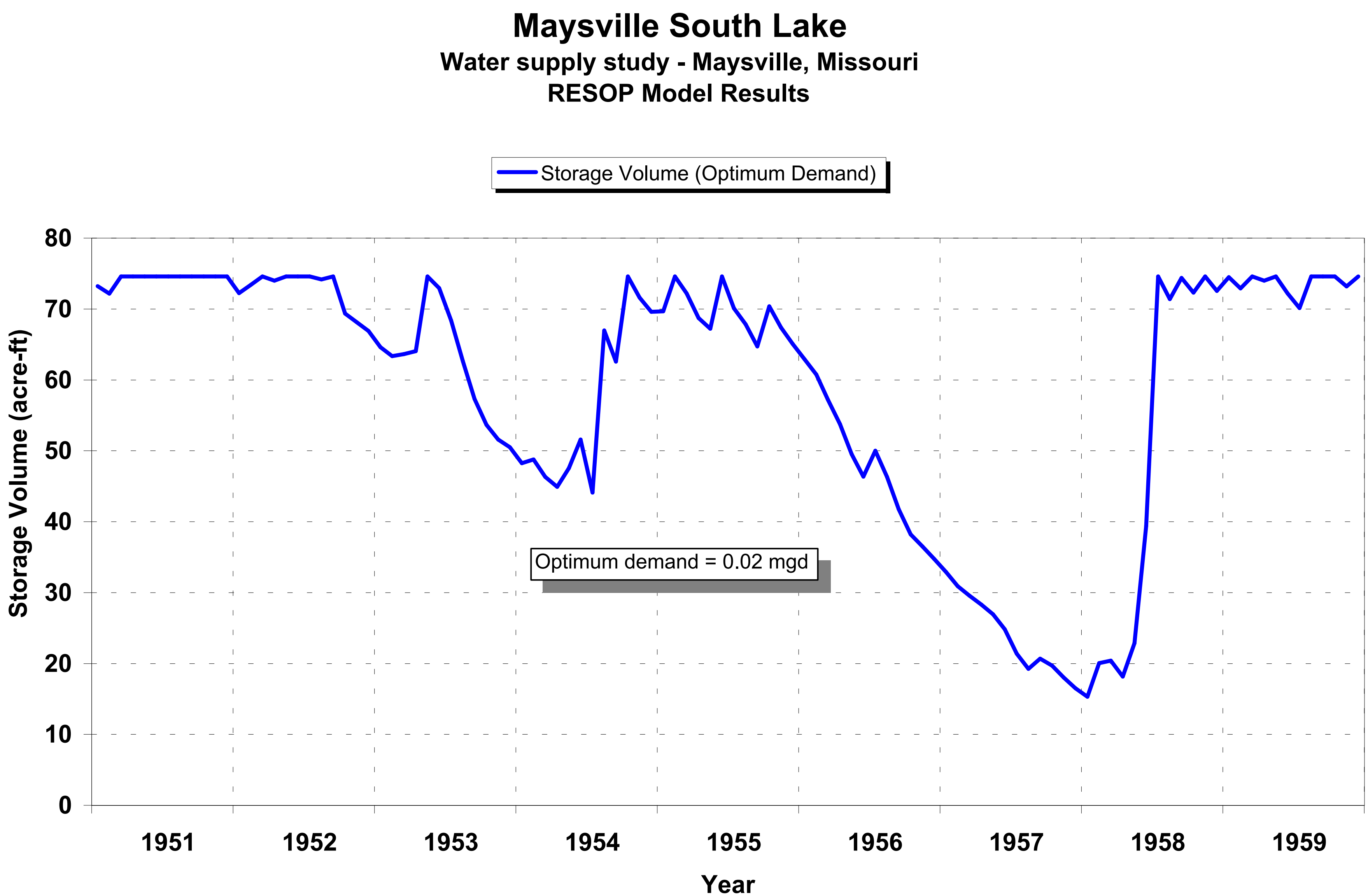

Maysville South Lake
Water supply study - Maysville, Missouri
RESOP Model Results
Storage Volume (Optimum Demand)
Optimum demand = 0.02 mgd
Storage Volume (acre-ft)
0
10
20
30
40
50
60
70
80
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 29.3.c

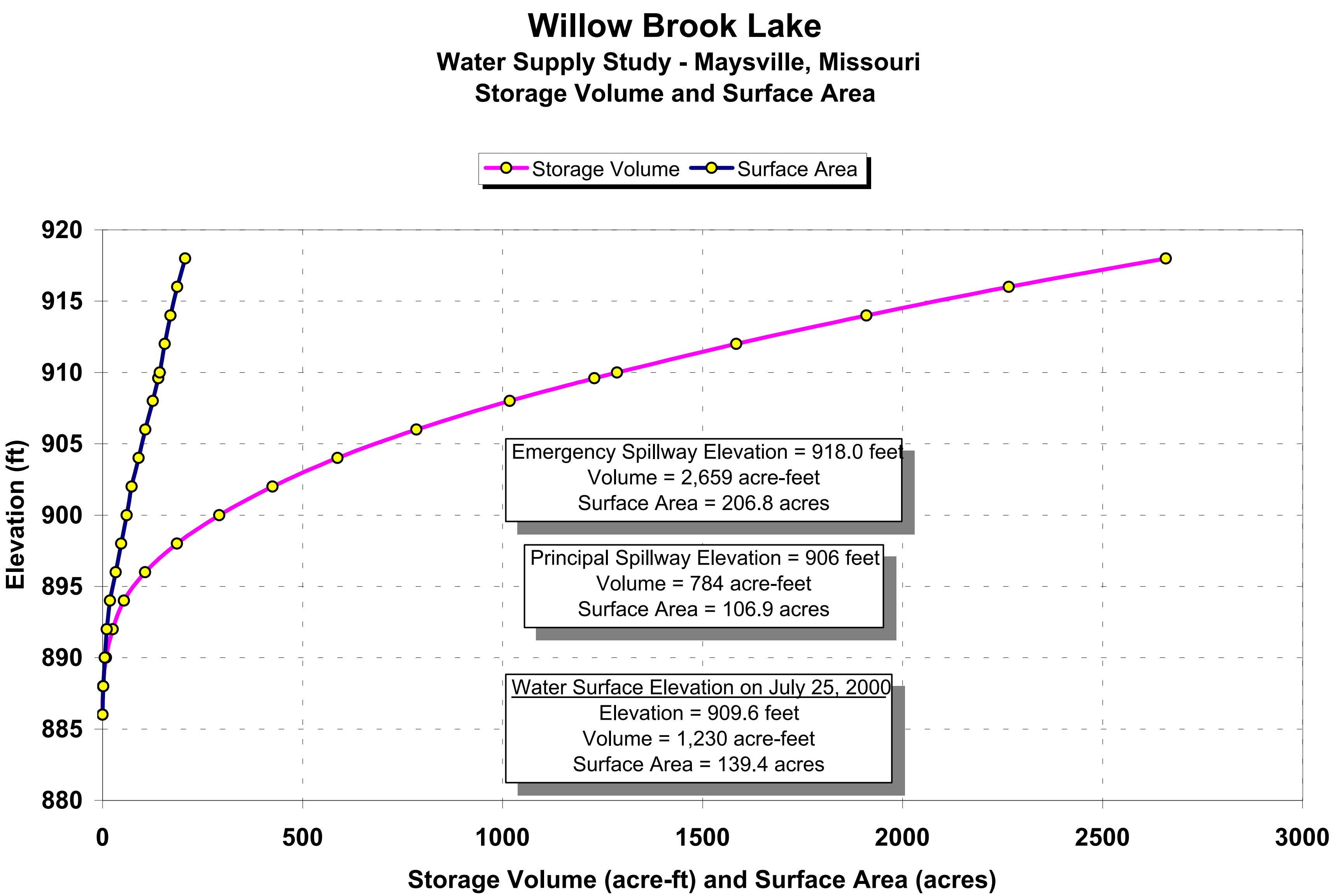

Willow Brook Lake
Water Supply Study - Maysville, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
920
915
910
905
900
895
890
885
880
Elevation (ft)
Emergency Spillway Elevation = 918.0 feet
Volume = 2,659 acre-feet
Surface Area = 206.8 acres
Principal Spillway Elevation = 906 feet
Volume = 784 acre-feet
Surface Area = 106.9 acres
Water Surface Elevation on July 25, 2000
Elevation = 909.6 feet
Volume = 1,230 acre-feet
Surface Area = 139.4 acres
0
500
1000
1500
2000
2500
3000
Storage Volume (acre-ft) and Surface Area (acres)

Figure 29.4.a

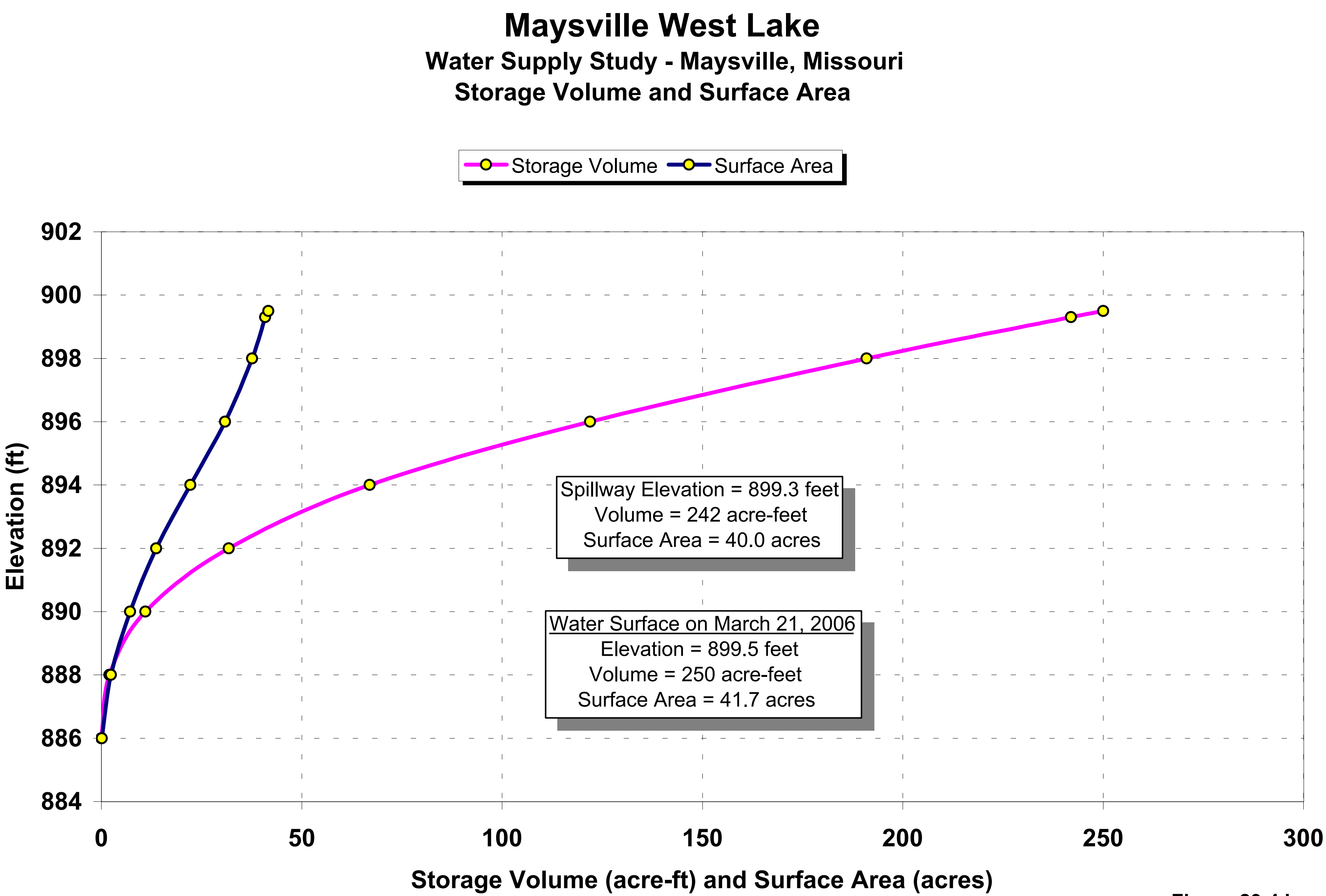

Maysville West Lake
Water Supply Study - Maysville, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Elevation (ft)
902
900
898
896
894
892
890
888
886
884
0
50
100
150
200
250
300
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 899.3 feet
Volume = 242 acre-feet
Surface Area = 40.0 acres
Water Surface on March 21, 2006
Elevation = 899.5 feet
Volume = 250 acre-feet
Surface Area = 41.7 acres

Figure 29.4.b

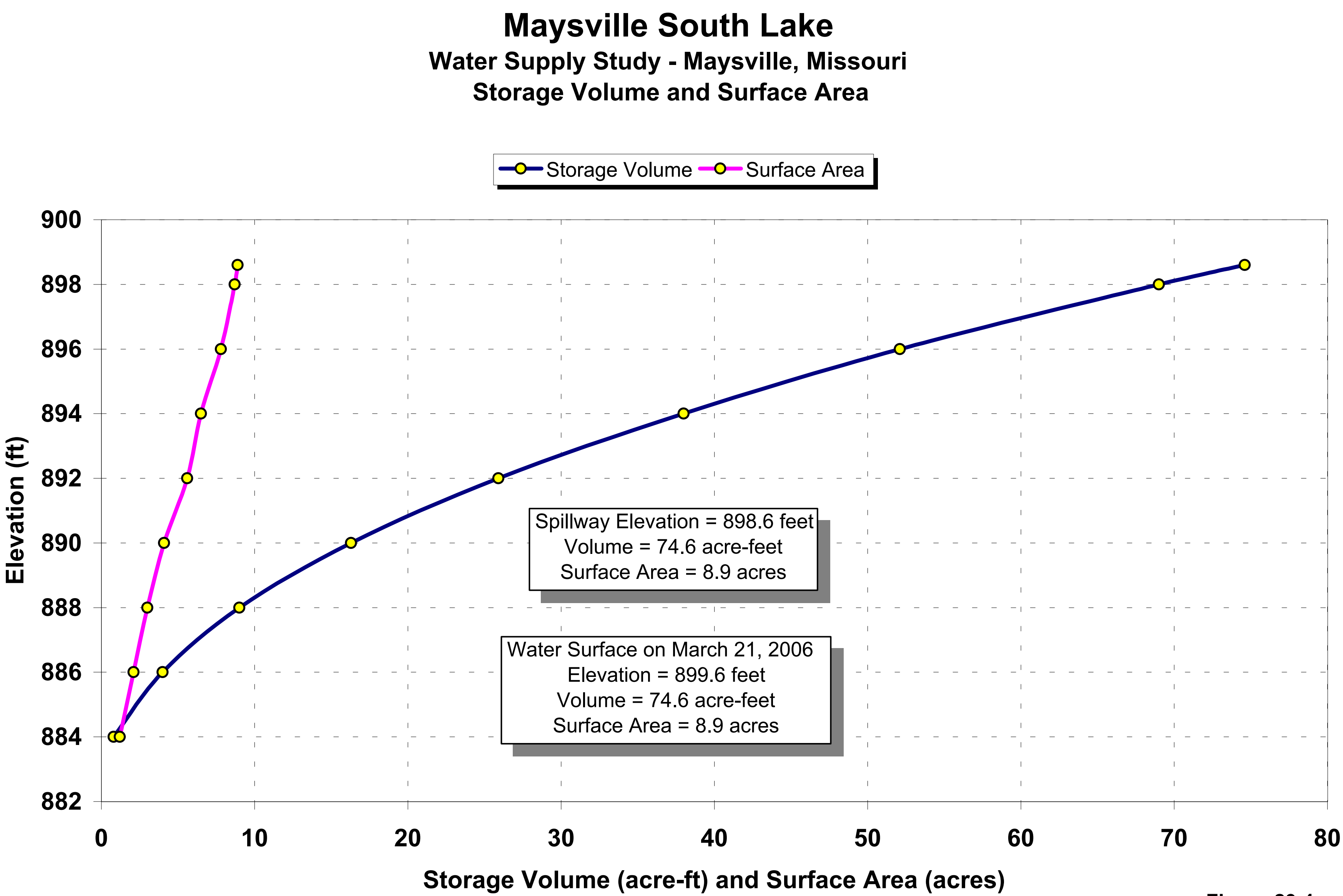

Maysville South Lake
Water Supply Study - Maysville, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
900
898
896
894
892
890
888
886
884
882
Elevation (ft)
0
10
20
30
40
50
60
70
80
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 898.6 feet
Volume = 74.6 acre-feet
Surface Area = 8.9 acres
Water Surface on March 21, 2006
Elevation = 899.6 feet
Volume = 74.6 acre-feet
Surface Area = 8.9 acres

Figure 29.4.c

Lake Show Me Reservoir and Old Memphis Reservoir
Water Supply Study – Memphis, Missouri
Drought Assessment Analysis

I. Overview

Lake Show Me Reservoir is located in Scotland County in northeast Missouri (figure 30.1.a). Lake Show Me supplies Memphis with their water demand. Memphis has two lakes that can provide water to the city. The Old Memphis Reservoir (figure 30.1.b) is downstream of Lake Show Me Reservoir. The Lake Show Me Reservoir serves a population of approximately 1,242 with an estimated water demand of 0.40 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

Lake Show Me Reservoir is located 3 miles west-south-west of Memphis while the Old Memphis reservoir is 1.7 miles south-west from Memphis. These reservoirs are on an unnamed tributary to North Fabius River. The drainage area for Lake Show Me is 2.66 square miles and the intervening drainage area for Old Memphis Reservoir is 1.51 square miles giving a total drainage area at the Old Memphis Reservoir of 4.17 square miles. Lake Show Me was surveyed June 3, 2002. The lower old lake was surveyed June 19, 2001. Old Memphis Reservoir is no longer used for water supply however can be used as a backup if needed. During large rainfall events discharge through Lake Show Me Reservoir's spillway was added to the inflow to the Old Memphis Reservoir.

Historical water demands on the Lake Show Me Reservoir is illustrated in figure 30.2. The 2000 demand for water was 0.42 million gallons per day and has been increasing at a rate of 2.8 percent per year since 1988.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was analyzed for Lake Show Me Reservoir. The model assumes that 'Normal' demand for Memphis in year 2000 was 0.42 million gallons per day and the 'Optimum' yield from the lake is 0.52 million gallons per day. Normal and optimum demands were calculated for Lake Show Me and only the optimum demand was evaluated of the old reservoir.

II. Drought Assessment Summary

In year 2000, Memphis used 153,276,495 gallons of water or 0.42 million gallons per day. Lake Show Me can meet this demand with 1630-acre feet remaining in the lake. Optimum demand is 0.78 million gallons per day. Only the optimum demand for the old lake was analyzed and determined to be 0.095 million gallons per day (figures 30.3.a and 30.3.b).

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from bathymetric surveys of Lake Show Me Reservoir and Old Memphis Reservoir. These were conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources for Lake Show Me on June 3, 2002 and Old Memphis Reservoir on June 19, 2001. Surface area of the lake and associated storage volume capacities are illustrated in figure 30.4

<u>Lake Show Me and Old Memphis Reservoirs Physical Data</u>

Lake Show Me Reservoir				***Old Memphis Reservoir***		
Elevation (feet)	Area (acres)	Volume (acre-feet)		(feet)	Area (acres)	Volume (acre-feet)
728	1.91	1.01		706	0.81	0.58
730	6.38	9.16		708	2.26	3.65
732	11.70	27.13		710	8.42	12.48
734	17.30	55.95		712	19.94	40.68
736	23.22	96.36		714	27.81	89.59
738	30.40	149.42		715	30.09	118.59
740	38.47	218.33		716	32.04	149.63
742	46.46	303.00		718	40.49	219.51
744	57.07	406.47		720	50.12	309.39
746	68.04	531.36		721	57.50	364.87
748	79.01	678.14				
750	91.64	848.42				
752	104.93	1,044.60				
754	119.12	1,268.72				
756	133.85	1,521.70				
758	149.19	1,804.49				
760	165.59	2,119.03				
762	181.47	2,465.87				
764	198.60	2,845.44				
766	214.18	3,258.52				
768	228.70	3,701.32				
769.8	244.93	4,125.81				
770	246.53	4,174.95				
772	262.08	4683.47				
774	278.41	5,223.82				

<u>Lake Show Me Reservoir</u>	<u>Old Memphis Reservoir</u>
Principal spillway elevation = 769.8 feet Lake conditions on June 3, 2002 = elevation 769.8 feet Emergency spillway elevation = 774 feet	Spillway elevation = 718 feet Lake conditions on June 19, 2001 Top of dam elevation = 721.5 feet

[LIMITS]

<u>Lake Show Me Reservoir</u>
Maximum storage……………………………………………………………4125.8 acre-feet
Minimum pool storage…………………………………………………………..50 acre-feet
Drainage basin size……………………………………………………2.66 square miles

Old Memphis Reservoir
Maximum storage……………………………………………………………219.5 acre-feet
Minimum pool storage……………………………………………………………..10 acre-feet
Drainage basin size………………………………………………………….1.51 square miles

Combined drainage area………………………………………………4.17 square miles

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Lake Show Me

Seepage from Lake Show Me is estimated to be 2.0 inches per month when at or near full capacity and approaches 0.0 as the reservoir is emptied. The seepage rate is a best estimate based on history of the reservoir, soil type, and material of the core of the dam. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible. When full the lake is about 40 feet deep, as a result the static pressure is fairly high and seepage is moderate.

Old Memphis Reservoir

Seepage from Old Memphis Reservoir is estimated to be 1.25 inches per month when at or near full capacity and approaches 0.0 as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation values for the drought of record came from Memphis, Missouri rain gauge.

Average precipitation in Memphis was 34.75 inches between 1950 and 2000. The most severe drought occurred between 1953 and 1957 with annual precipitation values of 23.23 inches, 33.25 inches, 28.95 inches, 24.29 inches, and 36.97 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Middle Fabius stream gauge, near Baring. The gauge is located approximately 8 miles south of Memphis. When this regional runoff value is inconsistent with precipitation values recorded for Memphis, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

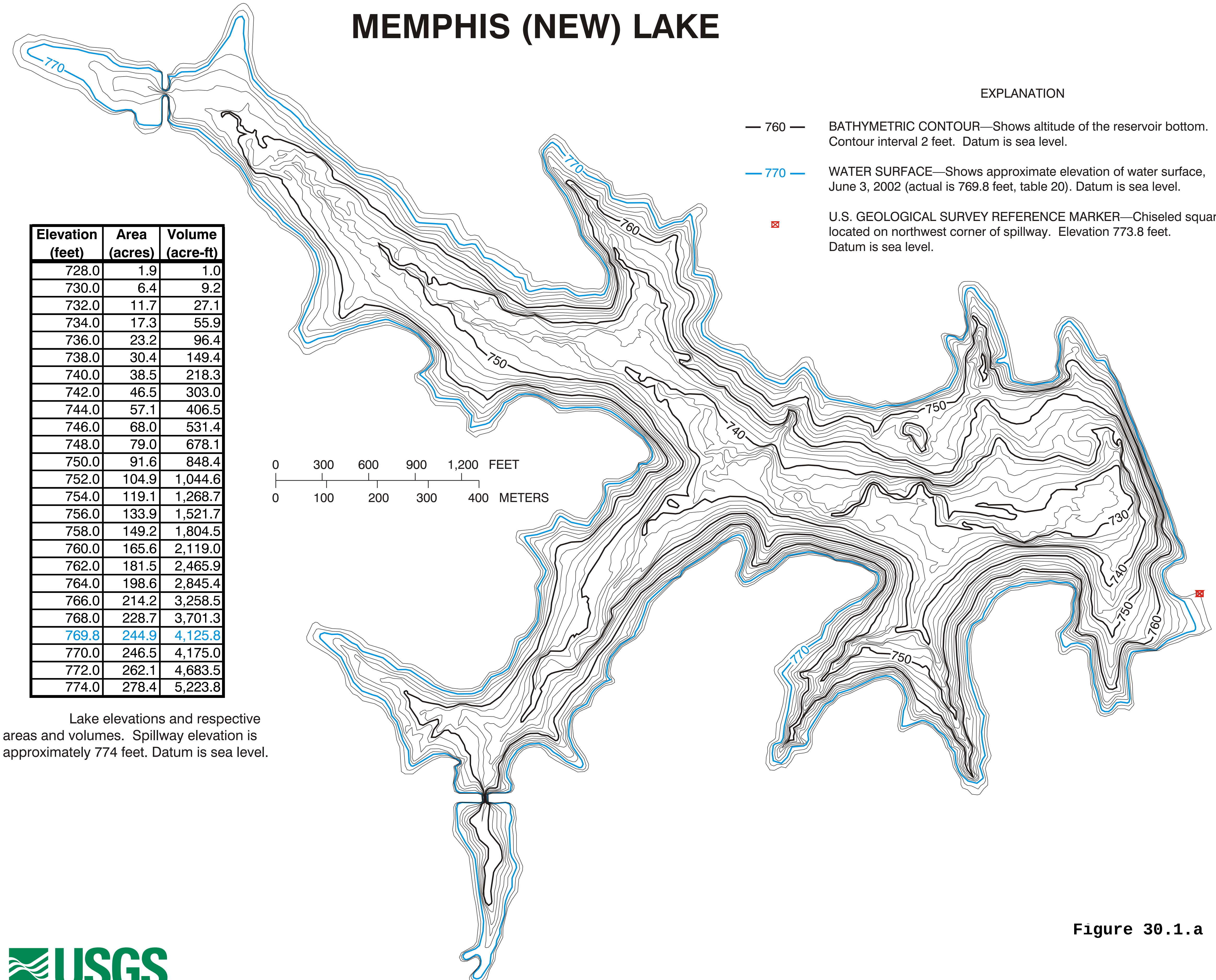
Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Lake Show Me and Old Memphis Reservoirs due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

Normal demand from Lake Show Me Reservoir for 2000 is 0.42 million gallons per day, and was used for this analysis.

City records reported to Missouri Department of Natural Resources ‘Major water users database were used to determined demand (figure 30.2).

MEMPHIS (NEW) LAKE



EXPLANATION

— 760 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

— 770 — WATER SURFACE—Shows approximate elevation of water surface, June 3, 2002 (actual is 769.8 feet, table 20). Datum is sea level.

U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on northwest corner of spillway. Elevation 773.8 feet. Datum is sea level.

Elevation (feet)	Area (acres)	Volume (acre-ft)
728.0	1.9	1.0
730.0	6.4	9.2
732.0	11.7	27.1
734.0	17.3	55.9
736.0	23.2	96.4
738.0	30.4	149.4
740.0	38.5	218.3
742.0	46.5	303.0
744.0	57.1	406.5
746.0	68.0	531.4
748.0	79.0	678.1
750.0	91.6	848.4
752.0	104.9	1,044.6
754.0	119.1	1,268.7
756.0	133.9	1,521.7
758.0	149.2	1,804.5
760.0	165.6	2,119.0
762.0	181.5	2,465.9
764.0	198.6	2,845.4
766.0	214.2	3,258.5
768.0	228.7	3,701.3
769.8	244.9	4,125.8
770.0	246.5	4,175.0
772.0	262.1	4,683.5
774.0	278.4	5,223.8

Lake elevations and respective areas and volumes. Spillway elevation is approximately 774 feet. Datum is sea level.

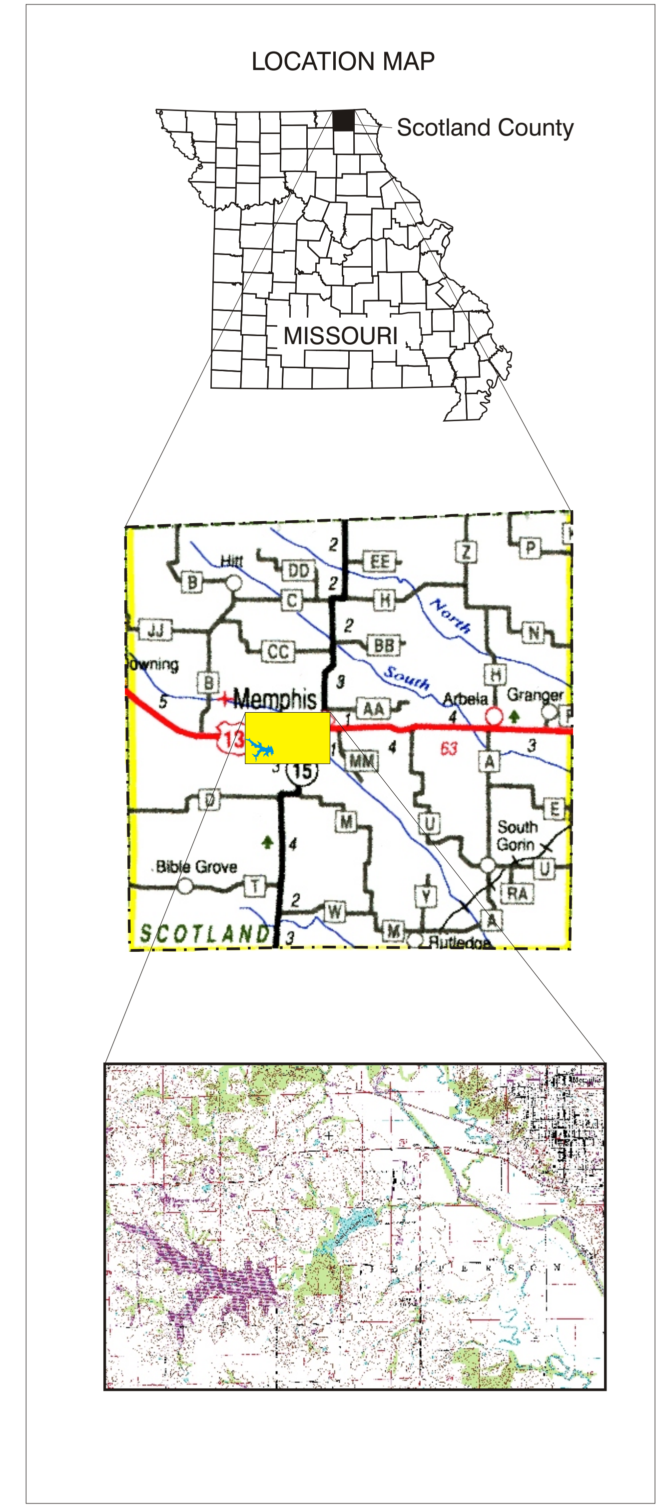


Figure 30.1.a

USGS
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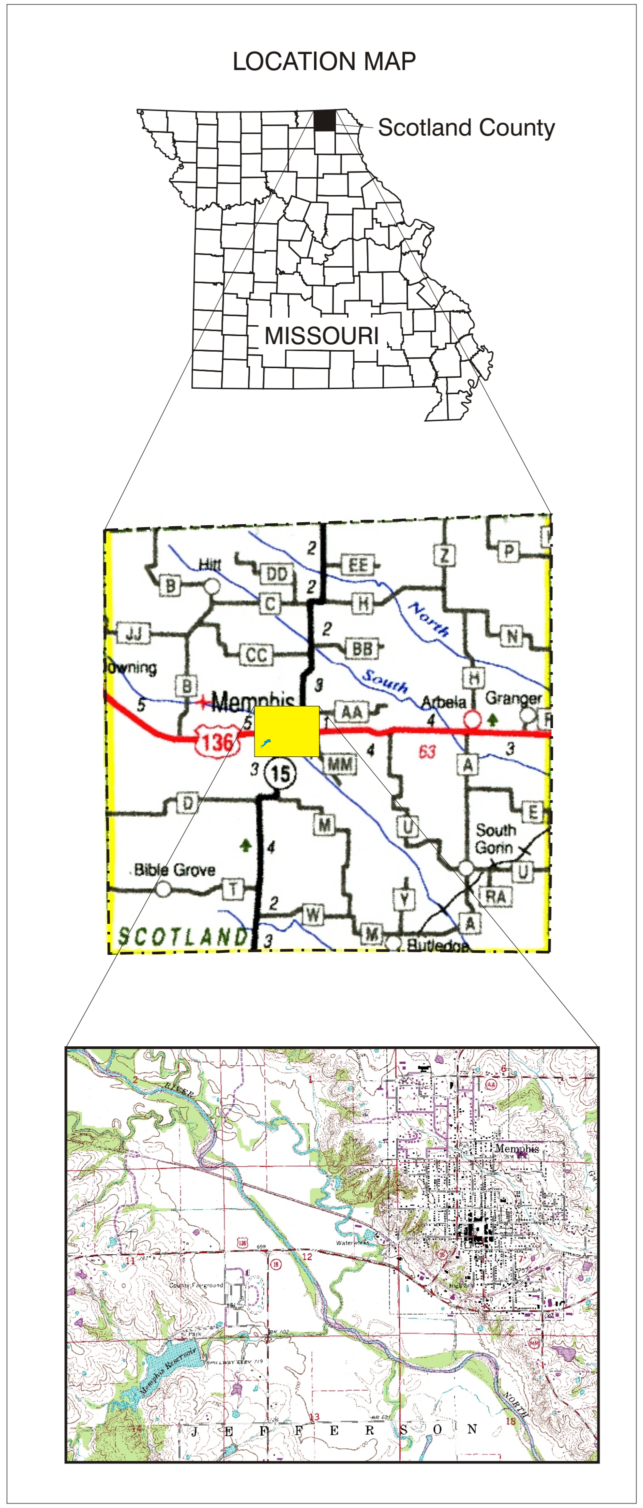
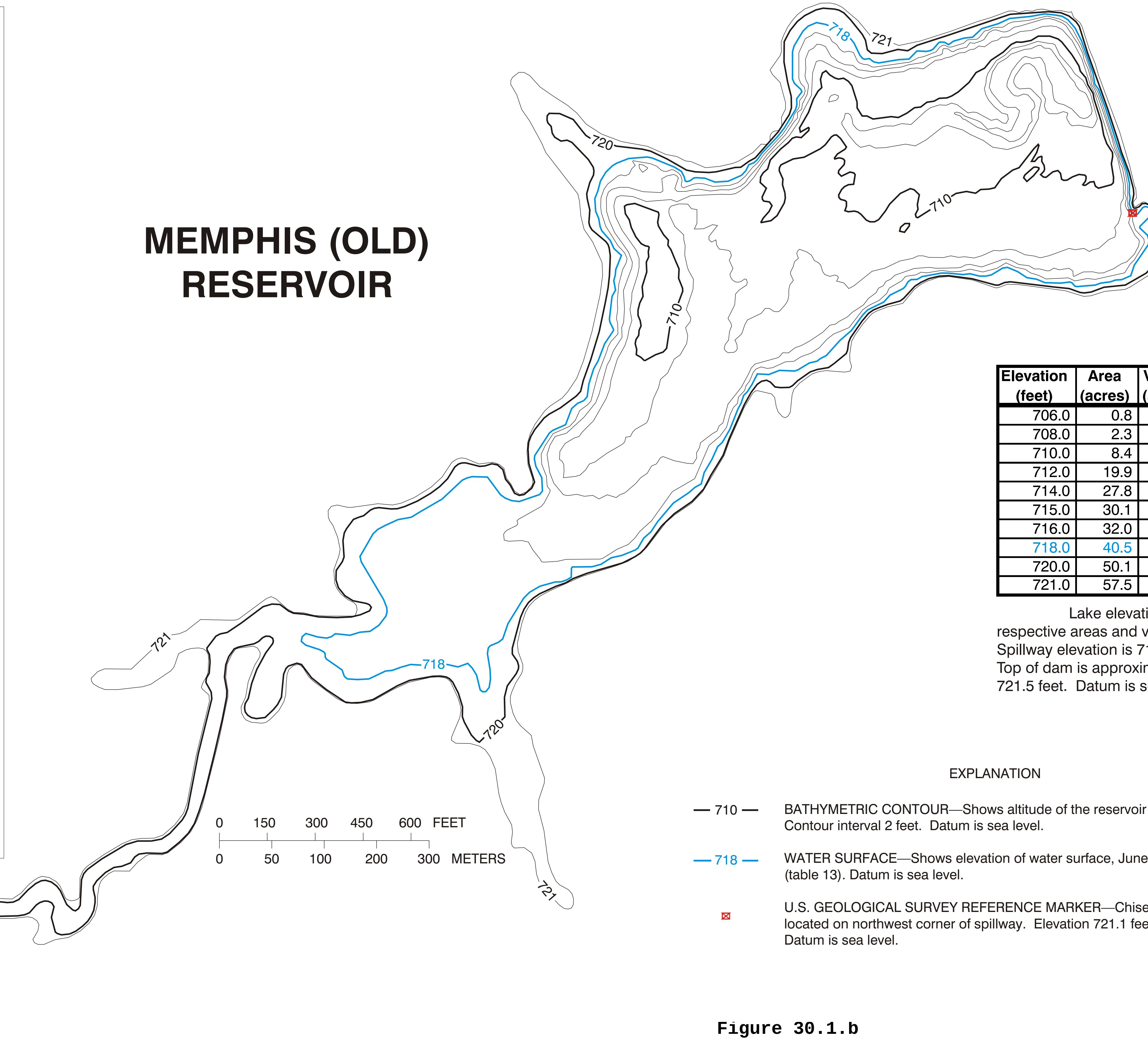
Bathymetric map and table of areas/volumes of the New Memphis Lake near Memphis, Missouri.



MEMPHIS (OLD) RESERVOIR



Elevation (feet)	Area (acres)	Volume (acre-ft)
706.0	0.8	0.6
708.0	2.3	3.7
710.0	8.4	12.5
712.0	19.9	40.7
714.0	27.8	89.6
715.0	30.1	118.6
716.0	32.0	149.6
718.0	40.5	219.5
720.0	50.1	309.4
721.0	57.5	364.9

Lake elevations and respective areas and volumes. Spillway elevation is 718.0 feet. Top of dam is approximately 721.5 feet. Datum is sea level.

EXPLANATION

— 710 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

— 718 — WATER SURFACE—Shows elevation of water surface, June 19, 2001 (table 13). Datum is sea level.

U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on northwest corner of spillway. Elevation 721.1 feet. Datum is sea level.

Figure 30.1.b

USGS
science for a changing world

Bathymetric map and table of areas/volumes of the Old Memphis Reservoir near Memphis, Missouri.

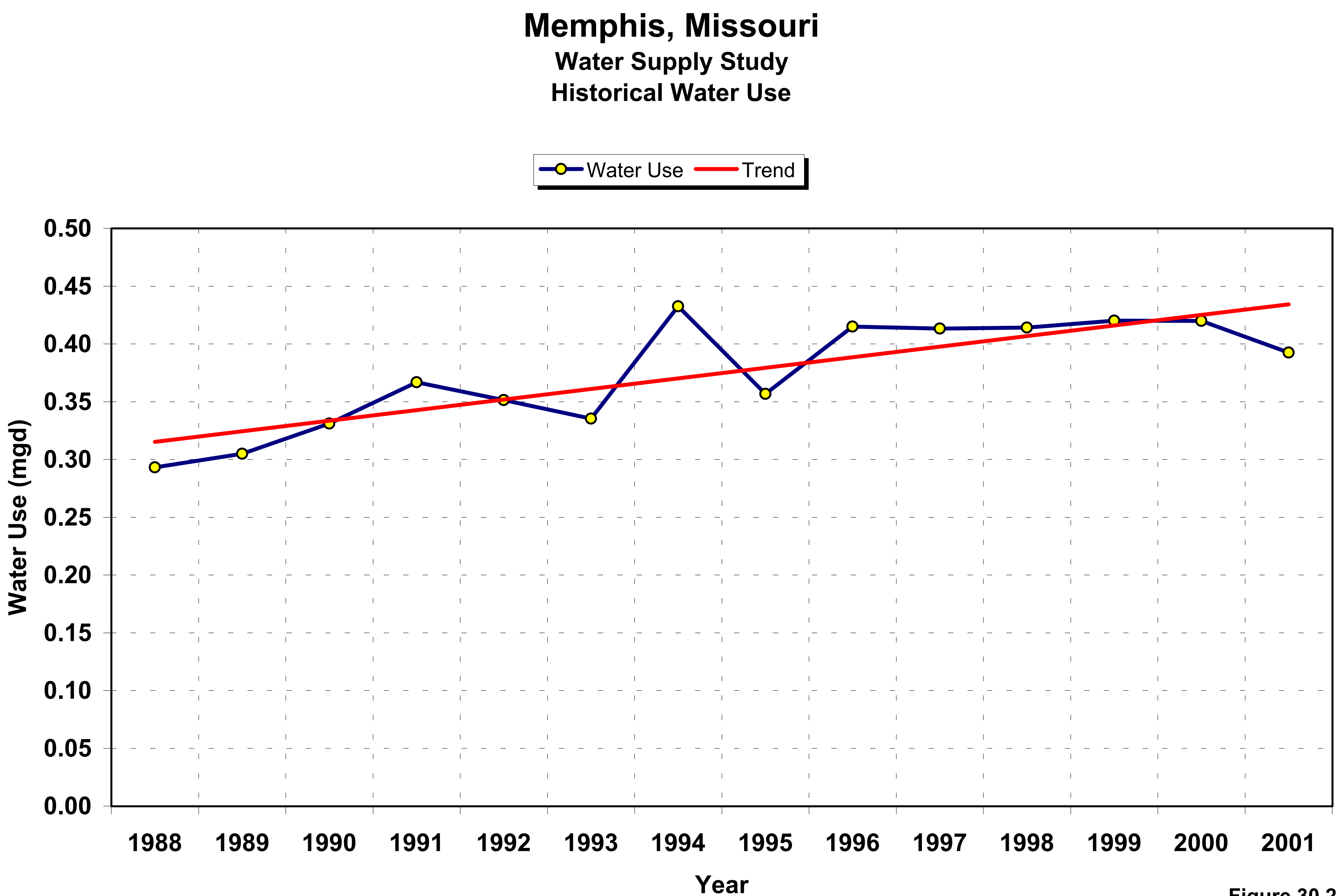

Memphis, Missouri
Water Supply Study
Historical Water Use
Water Use
Trend
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Water Use (mgd)
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 30.2

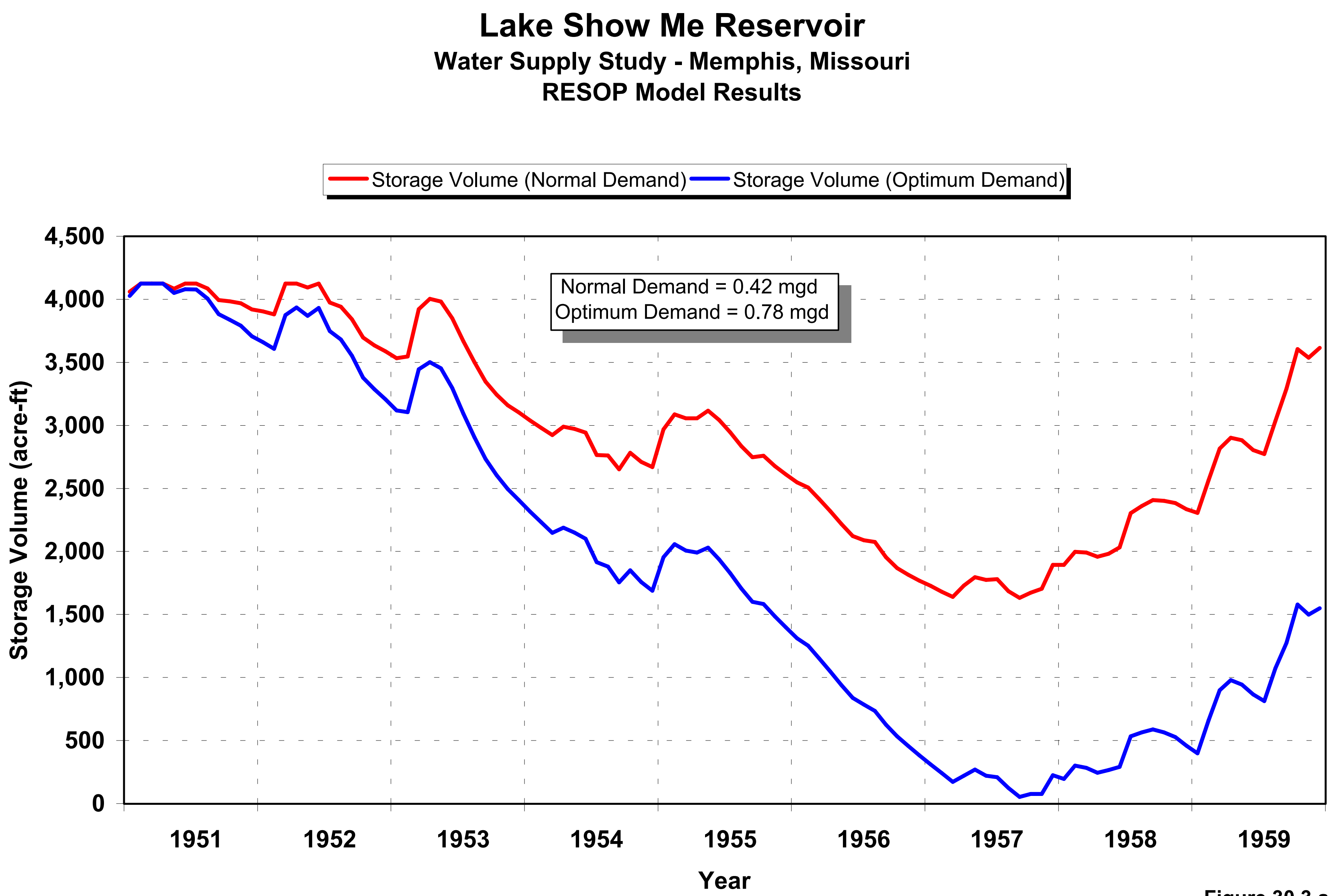

Lake Show Me Reservoir
Water Supply Study - Memphis, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 0.42 mgd
Optimum Demand = 0.78 mgd
Storage Volume (acre-ft)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 30.3.a

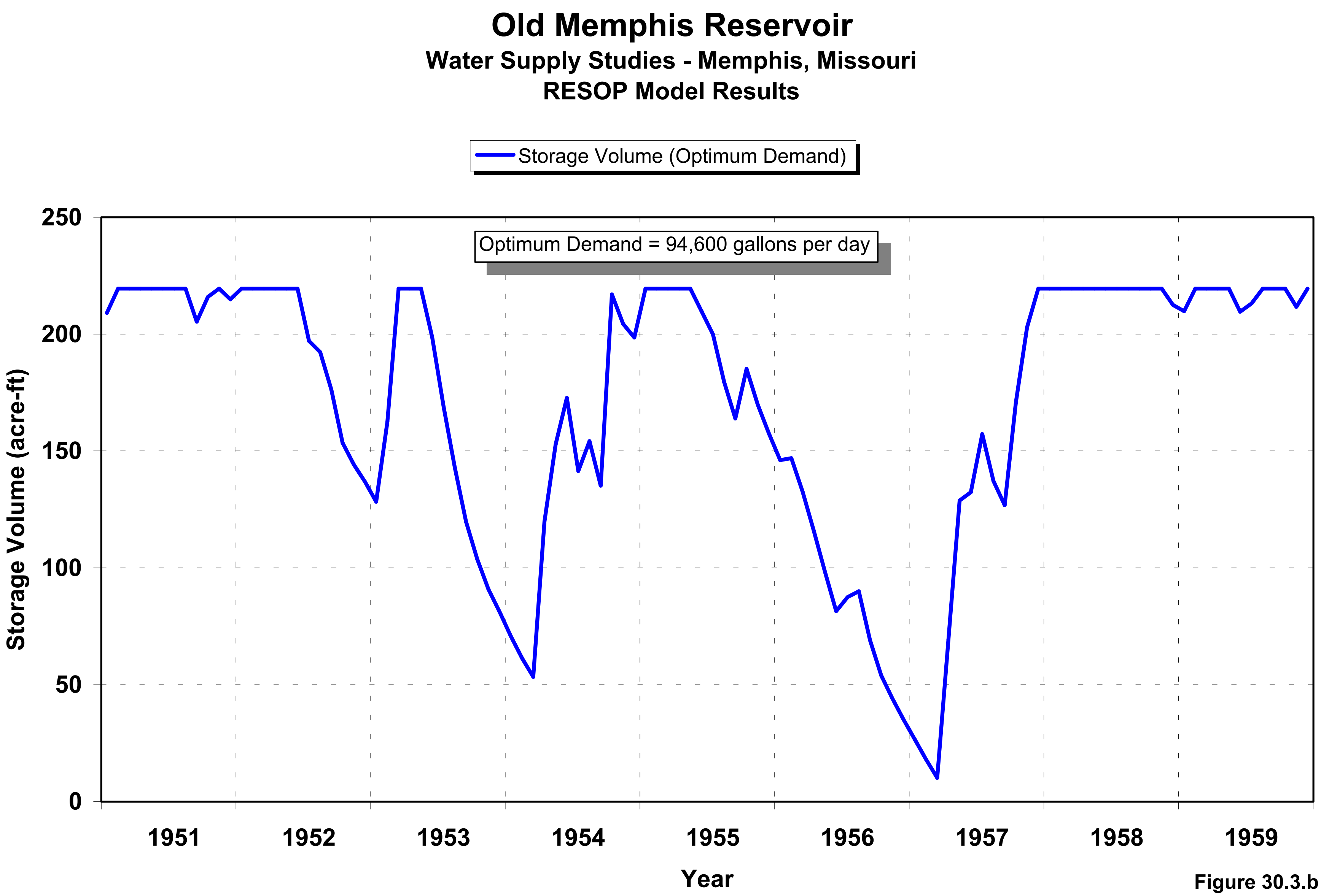

Old Memphis Reservoir
Water Supply Studies - Memphis, Missouri
RESOP Model Results
Storage Volume (Optimum Demand)
Optimum Demand = 94,600 gallons per day
Storage Volume (acre-ft)
250
200
150
100
50
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 30.3.b

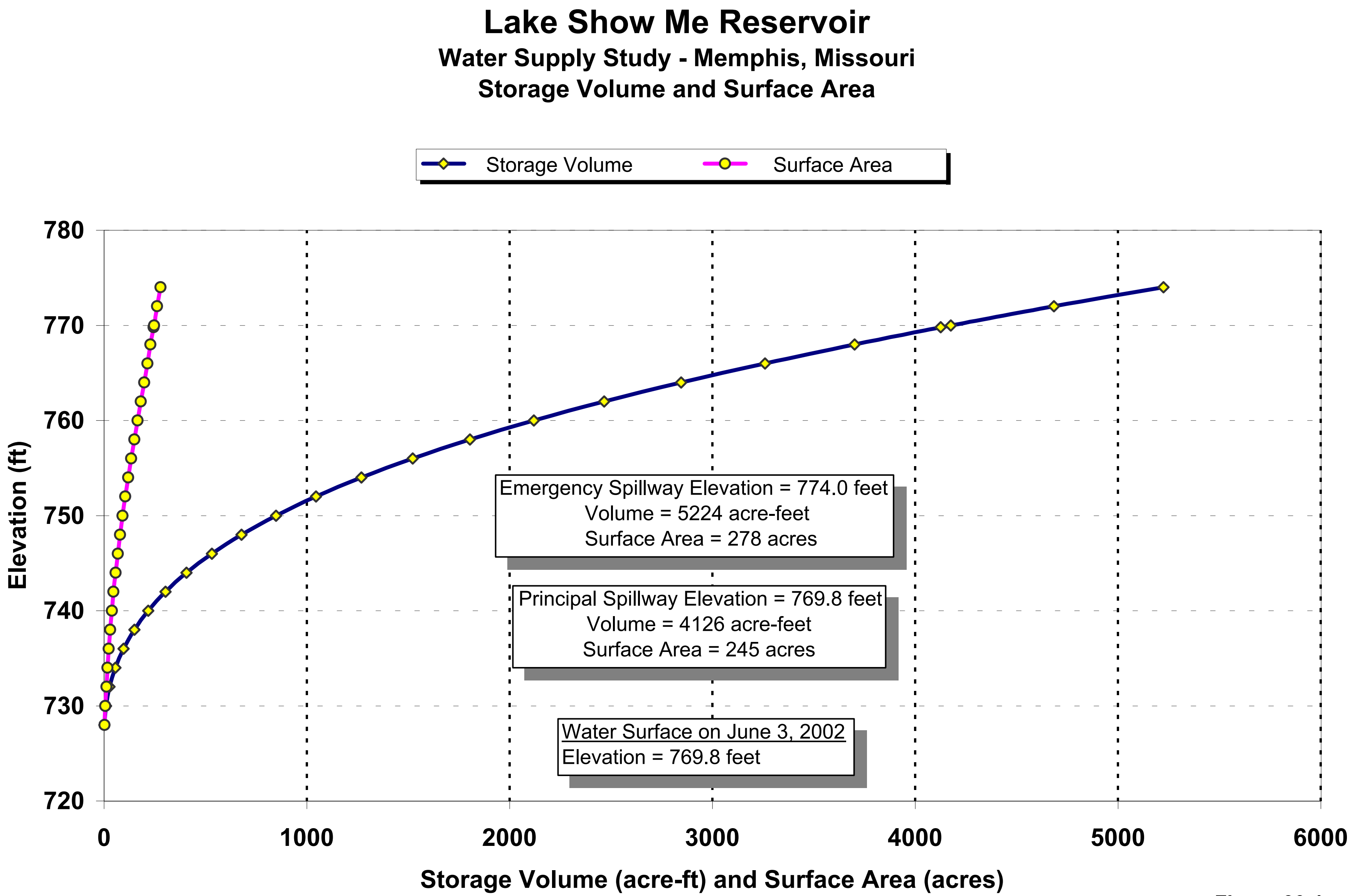

Lake Show Me Reservoir
Water Supply Study - Memphis, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Emergency Spillway Elevation = 774.0 feet
Volume = 5224 acre-feet
Surface Area = 278 acres
Principal Spillway Elevation = 769.8 feet
Volume = 4126 acre-feet
Surface Area = 245 acres
Water Surface on June 3, 2002
Elevation = 769.8 feet
Elevation (ft)
780
770
760
750
740
730
720
0
1000
2000
3000
4000
5000
6000
Storage Volume (acre-ft) and Surface Area (acres)

Figure 30.4.a

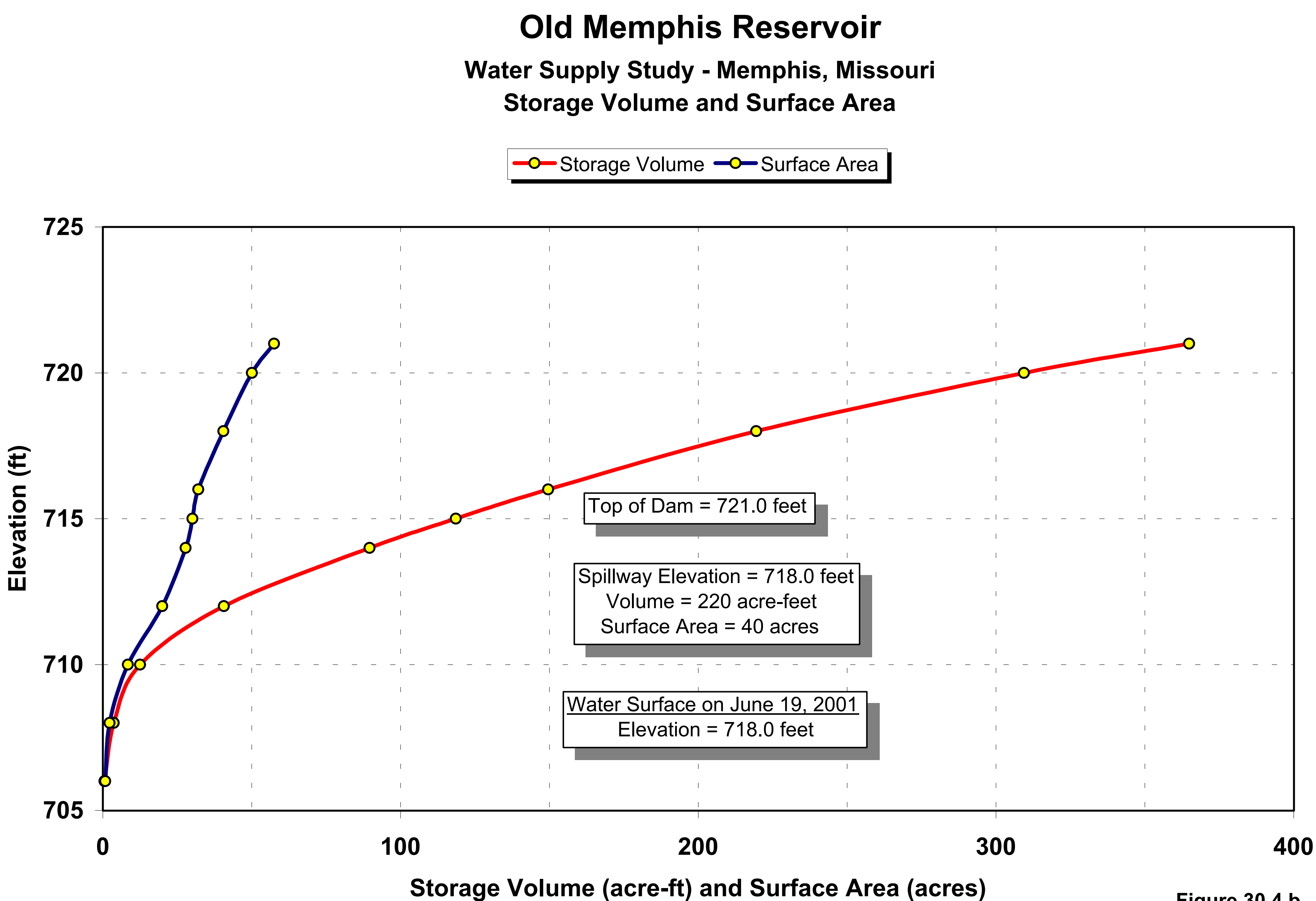

Old Memphis Reservoir
Water Supply Study - Memphis, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
725
720
715
710
705
Elevation (ft)
0
100
200
300
400
Storage Volume (acre-ft) and Surface Area (acres)
Top of Dam = 721.0 feet
Spillway Elevation = 718.0 feet
Volume = 220 acre-feet
Surface Area = 40 acres
Water Surface on June 19, 2001
Elevation = 718.0 feet

Figure 30.4.b

Middle Fork Grand River Reservoir
Water Supply Study – Middle Fork Water Company
Drought Assessment Analysis

I. Overview

Middle Fork Grand River Reservoir (figure 31.1) is located on Linn Creek, a tributary to Middle Fork Grand River, in Central Gentry County, Missouri, and approximately 7.5 miles northeast of the City of Stanberry. The reservoir drainage area is 6.3 square miles. The Middle Fork Water Company, who then sells water to Stanberry and Grant City, owns middle Fork Grand River Reservoir. Stanberry sells finished water to Gentry PWSD #2. Middle Fork Grand River Reservoir was constructed in 1995 and began selling water in 1996. The Middle Fork Reservoir serves a population of approximately 2,300 with an estimated water demand of 0.350 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

From 1996 through 2002 water use has had an average increase of four percent per year (figure 31.2). According to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Middle Fork Grand River Reservoir. The model assumes that ‘Normal’ demand 350,000 gallons per day and that ‘Optimum’ yield from the lake is 381,000 gallons per day. Figure 31.3 illustrates these relationships.

II. Drought Assessment Summary

The analysis shows that Middle Fork Grand River reservoir can meet the demand of 350,000 gallons per day through a drought of record through the 1950’s. There would be 75-acre feet remaining in the lake in February and March of 1957. Optimum demand is 381,000 gallons per day.

III. RESOP Model Parameters

Terms in brackets refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Middle Fork Grand River Reservoir (figure 31.1) conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on July 26, 2000. These relationships are illustrated in figure 31.4 for the lake.

Middle Fork Grand River Reservoir

Middle Fork Grand River Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
868.0	0.12	0.08	
870.0	1.70	0.99	Water Intake
872.0	5.70	7.32	
874.0	14.23	27.49	
876.0	24.36	65.35	
878.0	35.20	125.05	
880.0	48.37	208.90	
882.0	58.86	316.71	
884.0	69.36	443.30	
884.1	71.44	450.30	Lake Conditions on July 26, 2000
886.0	86.65	599.87	
888.0	108.97	794.15	
890.0	138.51	1040.67	
892.0	175.09	1352.91	
893.4	206.11	1625.01	Spillway

[LIMITS]

Maximum storage ....1625 acre-feet
Minimum storage ....20 acre-feet
Drainage basin size ....6.3 Square Miles

Initial storage volume was equated to the reservoir volume at lake conditions on July 26, 2000.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1952 through December 1960.

[SEEPAGE]

Seepage from Middle Fork Grand River Lake is approximately 2.5 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation data used for the analyses was recorded at the rainfall gauge located at White Cloud Creek stream gauge near Maryville.

Average precipitation in Maryville was 35.0 inches between 1950 and 2000. Precipitation values for the drought of record were obtained from White Cloud Creek gauge reporting station. The most severe drought occurred between 1953 and 1957 with annual precipitation values of 20.1 inches, 29.4 inches, 26.2 inches, 25.2 inches, and 34.4 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the White Cloud Creek stream gauge (a tributary of the 102 River) located near Maryville. The drainage area monitored by this stream gauge covers approximately 6.06 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Middle Fork Grand River, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Middle Fork Grand River Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

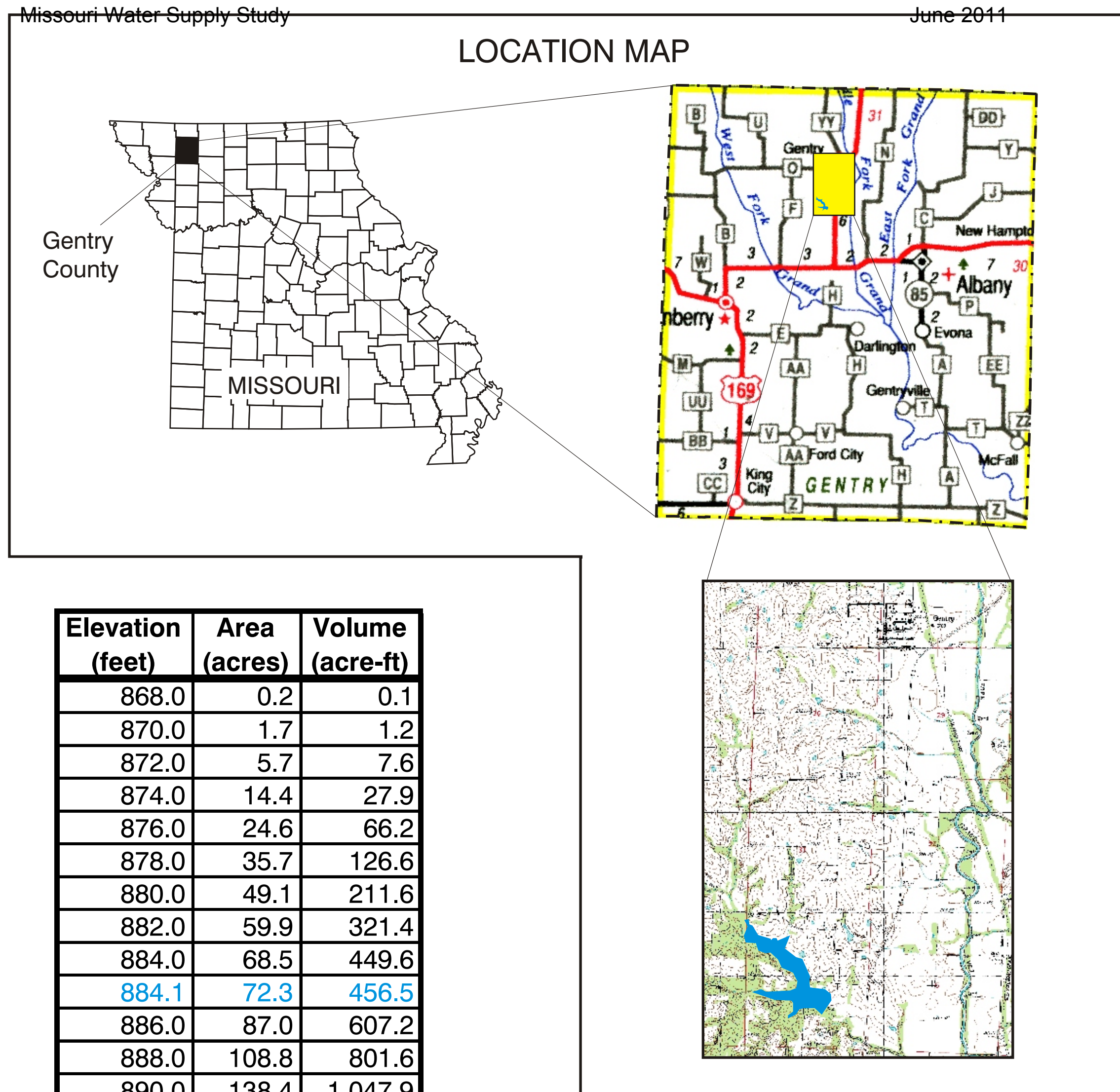
[DEMAND]

Water demand for this analysis was 350,000 gallons per day.

Water demand from Middle Fork Grand River Reservoir was provided from records maintained by Missouri Department of Natural Resources Kansas City Regional Office assisting Northwest Missouri. Records show the reservoir was providing an average of 350,000 gallons per day. Maximum daily recording was 450,000 gallons per day.

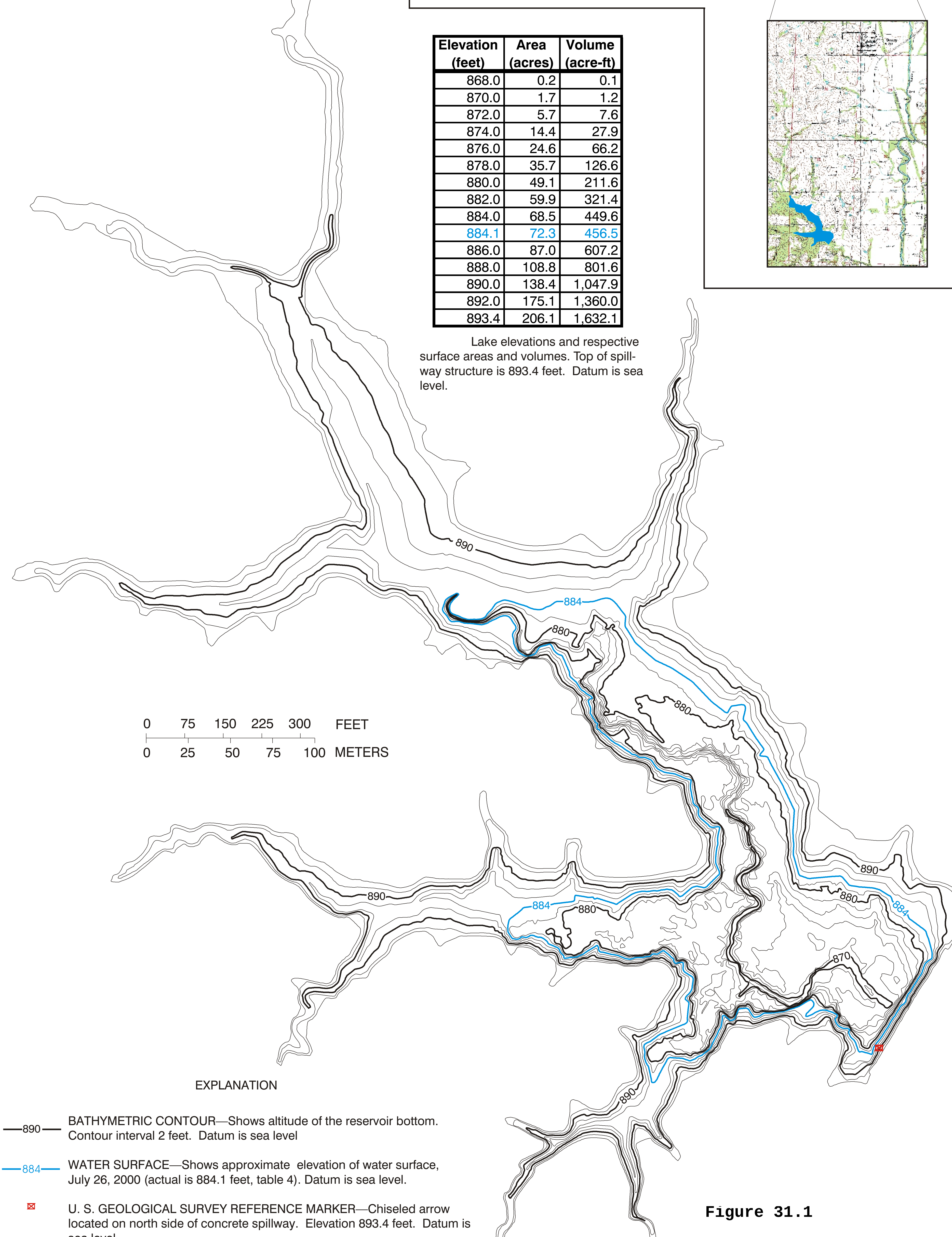
STANBERRY LAKE

Middle Fork Lake



Elevation (feet)	Area (acres)	Volume (acre-ft)
868.0	0.2	0.1
870.0	1.7	1.2
872.0	5.7	7.6
874.0	14.4	27.9
876.0	24.6	66.2
878.0	35.7	126.6
880.0	49.1	211.6
882.0	59.9	321.4
884.0	68.5	449.6
884.1	72.3	456.5
886.0	87.0	607.2
888.0	108.8	801.6
890.0	138.4	1,047.9
892.0	175.1	1,360.0
893.4	206.1	1,632.1

Lake elevations and respective surface areas and volumes. Top of spillway structure is 893.4 feet. Datum is sea level.



EXPLANATION

—890— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level

—884— WATER SURFACE—Shows approximate elevation of water surface, July 26, 2000 (actual is 884.1 feet, table 4). Datum is sea level.

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on north side of concrete spillway. Elevation 893.4 feet. Datum is sea level.

Figure 31.1

USGS science for a changing world

Bathymetric map and area/volume table of Middle Fork Water Company Lake Intake near Stanberry, Missouri.

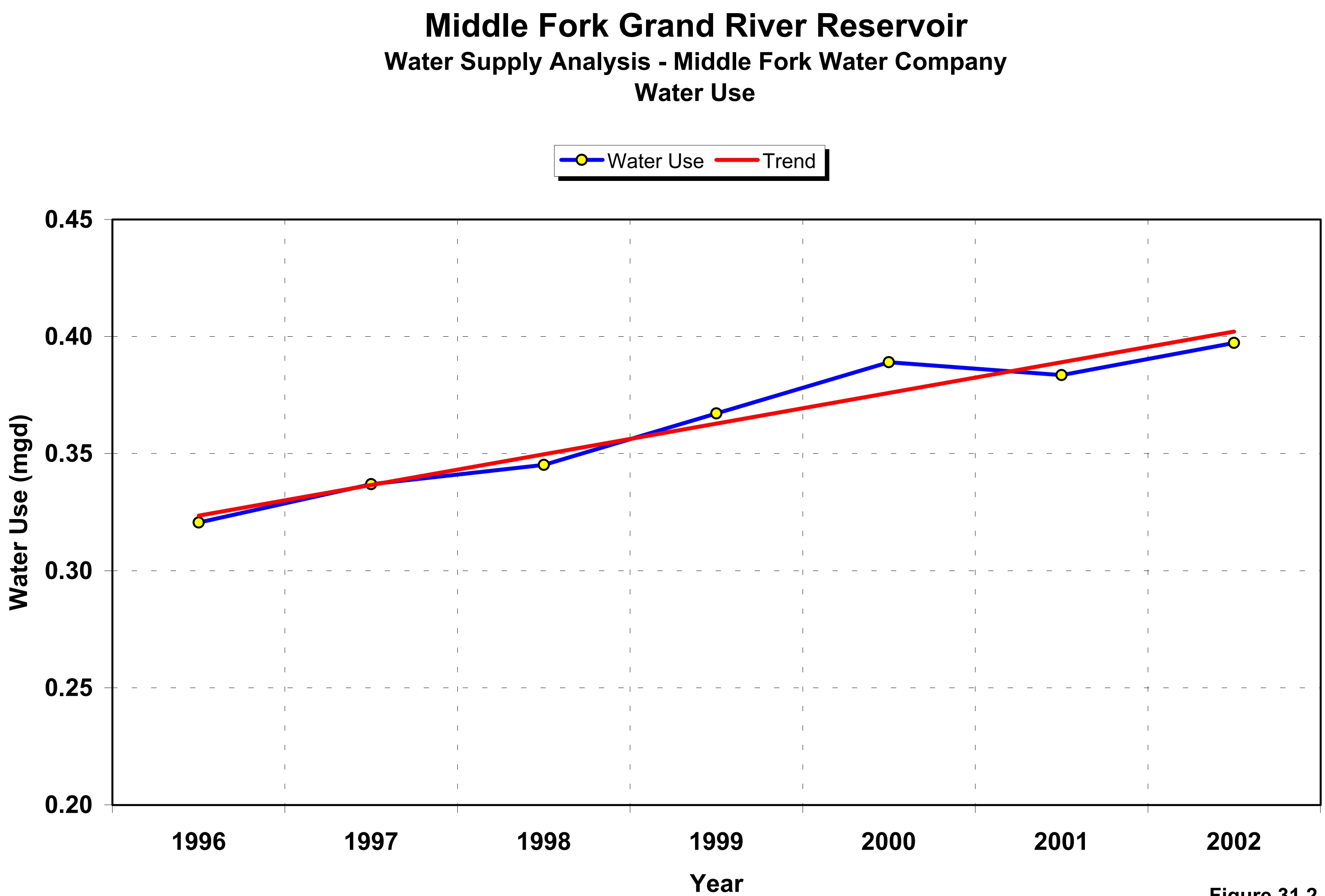

Middle Fork Grand River Reservoir
Water Supply Analysis - Middle Fork Water Company
Water Use
Water Use
Trend
0.45
0.40
0.35
0.30
0.25
0.20
Water Use (mgd)
1996
1997
1998
1999
2000
2001
2002
Year

Figure 31.2

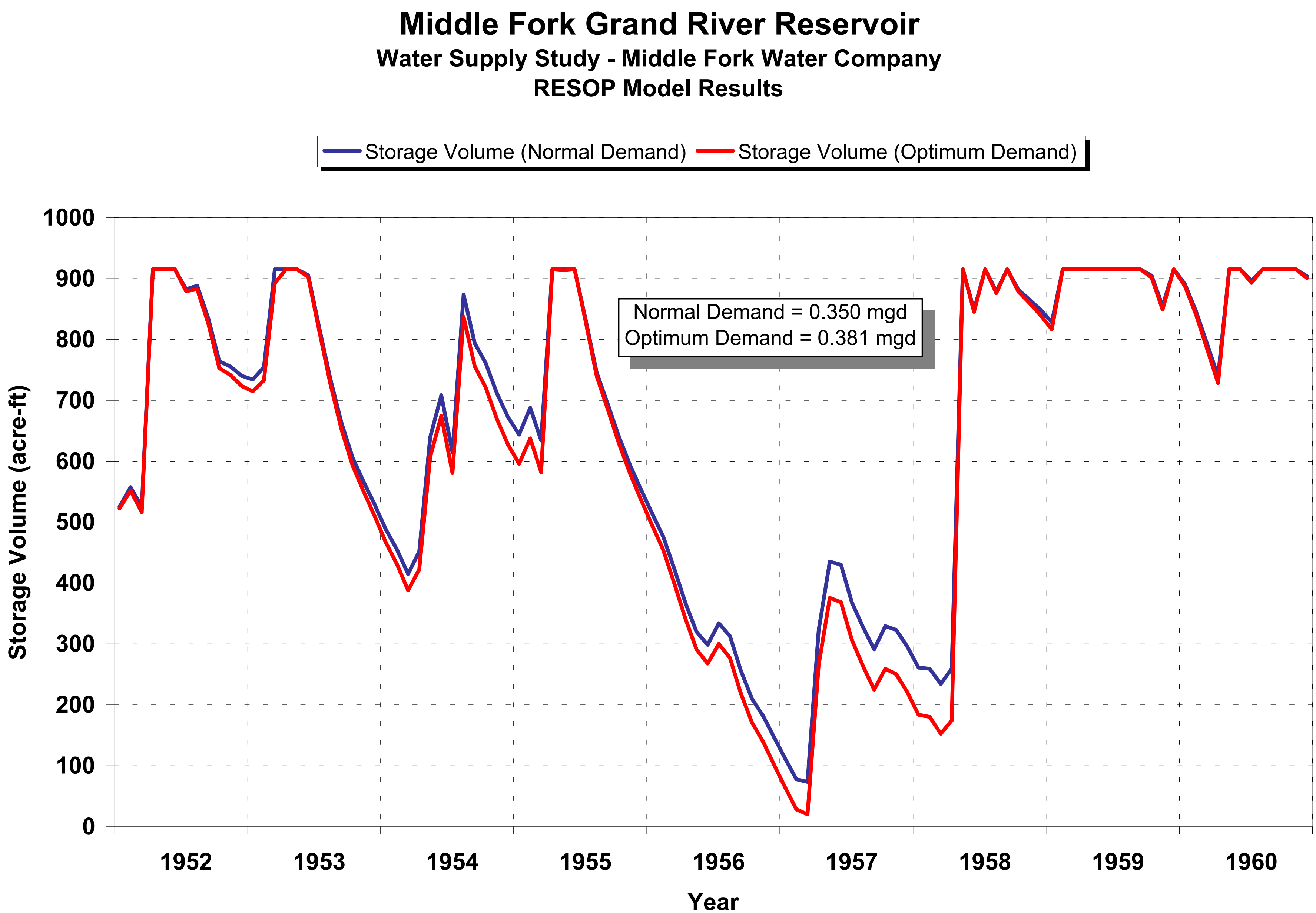

Middle Fork Grand River Reservoir
Water Supply Study - Middle Fork Water Company
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 0.350 mgd
Optimum Demand = 0.381 mgd
1000
900
800
700
600
500
400
300
200
100
0
Storage Volume (acre-ft)
1952
1953
1954
1955
1956
1957
1958
1959
1960
Year

Figure 31.3

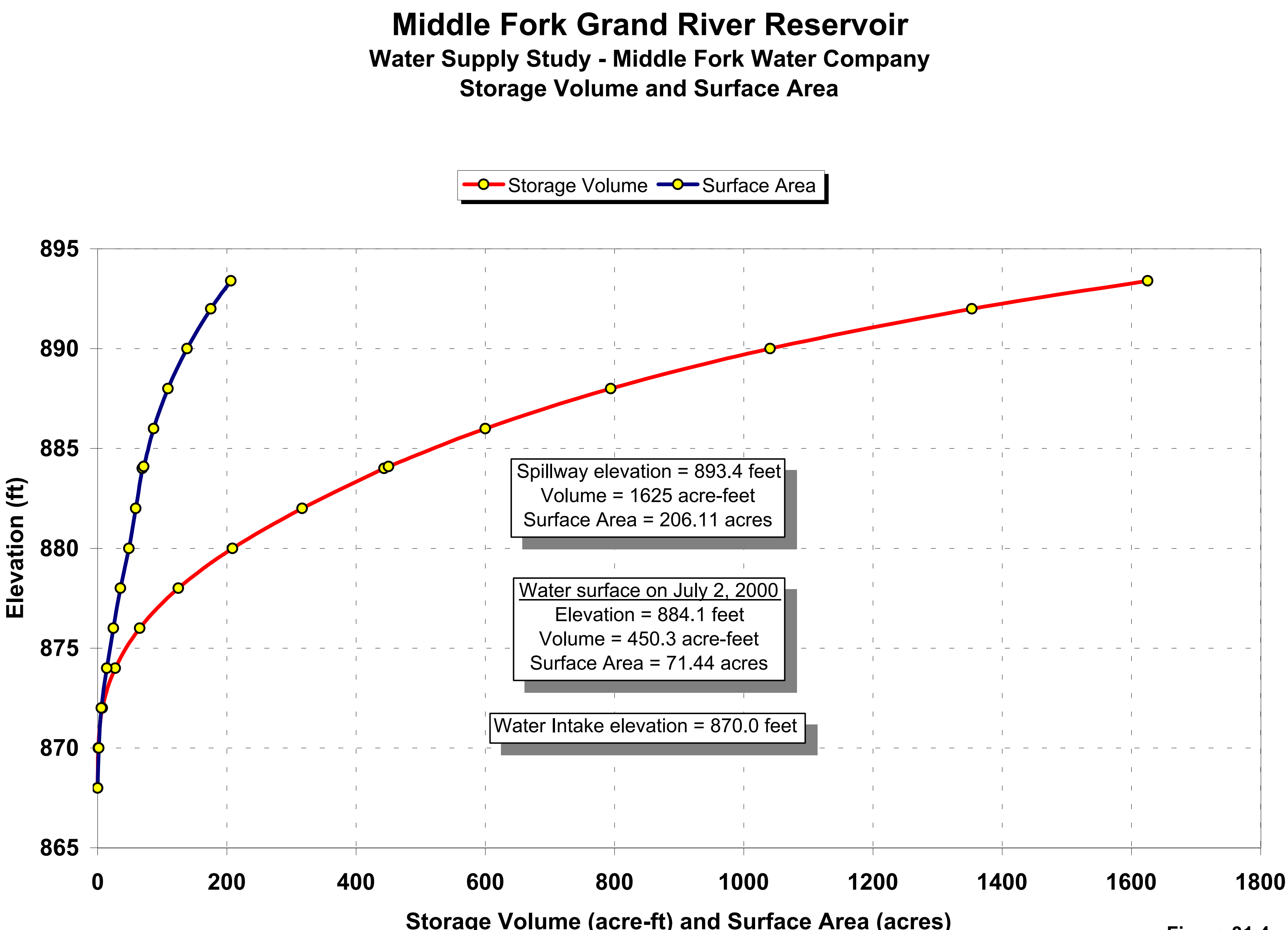

Middle Fork Grand River Reservoir
Water Supply Study - Middle Fork Water Company
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway elevation = 893.4 feet
Volume = 1625 acre-feet
Surface Area = 206.11 acres
Water surface on July 2, 2000
Elevation = 884.1 feet
Volume = 450.3 acre-feet
Surface Area = 71.44 acres
Water Intake elevation = 870.0 feet
Elevation (ft)
895
890
885
880
875
870
865
0
200
400
600
800
1000
1200
1400
1600
1800
Storage Volume (acre-ft) and Surface Area (acres)

Figure 31.4

Elmwood, Golf Course, and Shatto Reservoirs
Water Supply Study – Milan, Missouri
Drought Assessment Analysis

I. Overview

Milan is located in North Central Missouri, in central Sullivan County with East Locust Creek flowing along the eastern boundary of the city. Milan has two reservoirs available to use as water supply lakes. The larger one is Elmwood Reservoir (Figure 32.1.a), which is located about 2 miles North of Milan on a tributary to East Locust Creek. Golf Course Lake is an older lake and is located at Sullivan County Country Club near the city a short distance East of East Locust Creek (Figure 32.1.b). A third, Shatto Reservoir (figure 32.1.c) is a privately owned lake located to the south of Milan. It is not used for water supply and was investigated to determine the volume of water availability for emergency water supply. Shatto Lake is a 34-acre lake, which has too small of a drainage area, 173 acres, to provide a dependable source of water. The Milan Reservoir system serves a population of approximately 2,125 with an estimated water demand of 0.716 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

At the time of this report, year 2000, Milan was experiencing severe water shortage. They had nearly emptied both lakes and were diverting water from Locust Creek at a site west of Milan. They have been using an average of 1.65 million gallon per day (figure 32.2). A 3000-gallon per minute pump was used for pumping from Locust Creek. Prior to 2003 Milan was using a maximum of 1.13 million gallons per day with an average annual increase from 1887 through 2004 of 5.5 percent.

Storage in Elmwood Lake has been increased in recent years to provide water to a poultry-processing plant as well as untreated water for Premium Standard Farms meat processing plant in addition to the cities needs. A rural water district has been removed from the system to conserve water. Before the lake was modified, it had significant leakage. Leakage has now been greatly reduced. Premium Standard Farms purchases untreated water from Milan for their hog processing plant where they provide their own water treatment.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Elmwood Reservoir model consisted of a normal demand of 1.65 million gallons per day which could not be met and the optimum demand was determined to be 0.737 million gallons per day. To meet the normal demand water was added to the reservoir by diverting from Locust Creek. Golf Course modeling consisted of a normal demand of 0.400 million gallons per day. Golf Course Reservoir demand of 0.40 million gallons per day could not be met and the optimum analysis resulted in an average demand of 0.116 million gallons per day. Shatto Reservoir analysis consisted of determining the optimum demand of 0.083 million gallons per day. Figures 32.3.a, 32.3.b, and 32.3.c illustrate these results.

Plans have been prepared to develop a regional water supply lake through the Natural Resource Conservation Service (NRCS) small watershed (PL-566) program. This multipurpose reservoir, located 4.5 miles north of Milan has a drainage area of 32.8 square miles, The East Locust Creek PL-566 watershed plan was supplemented to include this multipurpose reservoir that will provide 7 million gallons per day of water supply through the drought of record. This multipurpose reservoir was not considered part of this analysis.

II. Drought Assessment Summary

The optimum demand from Elmwood Reservoir averages 0.737 million gallons per day, and Golf Course Reservoir can be expected to yield and average of 0.116 million gallons per day. The total for both lakes is 0.853 million gallons per day. This is far short of the demand, 1.65 million gallons per day, placed on the system. To meet the demand a 3000 gallons per minute pump is used to pipe water from Locust Creek to Elmwood Reservoir. Pumping when sufficient flow exists in Locust Creek will allow 1.65 million gallons per day to be met.

Golf Course reservoir has a normal demand of 0.400 million gallons per day. Golf Course Reservoir demand of 0.40 million gallons per day could not be met and the optimum analysis resulted in an average demand of 0.116 million gallons per day.

Because there is no daily demand placed on Shatto Reservoir only an optimized run was made. The daily volume of water available is 83,000 gallon per day. By removing water at this rate the lake would be emptied and have no opportunity to refill until some time after 1960's.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Elmwood and Golf Course Reservoirs conducted by the Natural Resource Conservation Service during May 2000. Surface area of the lake and associated storage volume capacities are illustrated in figures 32.4.a, 32.4.b.

Volume and surface area data for Shatto Reservoir were derived from a bathymetric survey conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on July 20, 2000 and illustrated in figure 32.4.c.

Elmwood and Golf Course Reservoirs Physical Data

Elmwood Reservoir				**Golf Course Reservoir**		
Elevation (feet)	Area (acres)	Volume (acre-ft)		Elevation (feet) assumed	Area (acres)	Volume (acre-ft)
842	0.25	0		64	0.21	0
844	0.93	1.19		66	2.61	2.82
846	1.60	3.72		68	4.89	10.31
848	4.58	9.91		70	7.95	23.16
850	20.04	34.53		72	11.00	42.11
852	32.17	86.75		74	14.67	67.77
854	46.45	165.37		76	17.88	100.32
856	63.37	275.19		78	20.97	139.17
858	78.34	416.91		80	25.02	185.15
860	94.06	589.32		82	29.54	239.70
862	113.13	796.51		84	34.70	303.94
864	137.94	1047.59		84.6	36.41	325.27
866	154.61	1340.14		86	38.63	377.80
868	170.09	1664.84		88	41.96	458.40
870	202.02	2036.95		90.1	50.24	555.21
872.2	221.85	2503.21				

Spillway Elevation = 872.0 feet Volume = 2503 acre-feet Surface Area = 222 acres Water Surface on May 25, 2000 Elevation = 684.0 feet Volume = 1074 acre-feet Surface Area = 138 acres	Spillway Elevation = 90.1 feet Volume = 555.2 acre-feet Surface Area = 50 acres Water Surface on May 2, 2000 Elevation = 84.6 feet Volume = 325.2 acre-feet Surface Area = 36.4 acres

Shatto Reservoir Physical Data

Shatto Reservoir			
Elevation (feet)	Area (acres)	Storage (acre-feet)	Additional Notes
846	0.19	0.18	
848	0.47	0.75	
850	1.15	2.44	
852	1.89	5.48	
854	2.59	9.96	
856	3.24	15.78	
858	4.27	23.28	
860	5.45	33.01	
862	6.86	45.26	
864	8.42	60.51	
866	10.03	78.93	
868	11.57	100.56	
870	13.08	125.19	
872	14.62	152.90	
874	16.40	183.80	
876	18.60	218.80	
878	20.56	258.00	
880	22.38	300.92	
882	24.22	347.55	
884	25.75	397.51	
886	27.33	450.55	
888	29.00	506.92	
890	30.49	566.41	
890.3	30.76	575.59	Lake condition July 20, 2000
892	32.02	628.98	
893	32.80	661.37	
894	33.51	694.53	
895.6	34.68	749.08	Top of Dam

[LIMITS]

Elmwood Reservoir
Maximum storage……………………………………………..…………………2503 acre-feet
Minimum storage ……………………………………………………..…………..417 acre-feet
Drainage basin size…………………………………………………………..…..6.41 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

Golf Course Reservoir
Maximum storage……………………………………………………………….….555 acre-feet
Minimum pool storage……………………………………………………………162 acre-feet
Drainage basin size..……………………………………………………..1.06 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

Shatto Reservoir
Maximum storage…………………………………………………………….....661 acre-feet
Minimum storage…………………………………………………………………80 acre feet
Drainage basin size……………………………………………………………..173 acres

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Elmwood Reservoir is estimated to be 3.0 inches per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. Seepage from Golf Course Reservoir is estimated to be 1.5 inches per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied.

These two reservoirs are bound by earthen dams composed of compacted clay-rich materials - seepage through the dams is considered negligible.

Seepage from Shatto Reservoir is estimated to be 3.0 inches per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. Owners have not been completely successful in sealing off a leak at the base of the dam.

[RAINFALL]

Precipitation values for the drought of record were obtained from Milan, Missouri

Average precipitation in Milan was 37.2 inches between 1950 and 2000. The most severe drought occurred between 1952 and 1957 with annual precipitation values in Milan of 28.01 inches, 26.22 inches, 34.07 inches, 36.22 inches, and 29.03 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Locust Creek stream gauge near Linneus.

The drainage area monitored by this stream gauge covers approximately 550 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Milan, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Elmwood, Golf Course and Shatto Reservoirs due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New

Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

Water demand was obtained from records reported by the city records to Missouri Department of Natural Resources "Major Water Users Data Base". Their water use has increased significantly because of Premium Standard Farms hog processing plant and the poultry processing plant. This analysis used a total of 1.65 million gallons per day.

The average daily demand by use in year 2000 follows:

Milan treatment plant production
PWSD#1…………………………………….300,000 gallons per day…………..0.92 acre-feet.
Poultry processing…………………………353,000 gallons per day…………..1.08 acre-feet.
City use……………….……………………..297,000 gallons per day…………..0.91 acre-feet.
Total finished water..…..…………………..950,000 gallons per day..…………2.91 acre-feet.

Raw water to PSF…………………………700,000 gallons per day…..………2.15 acre-feet.

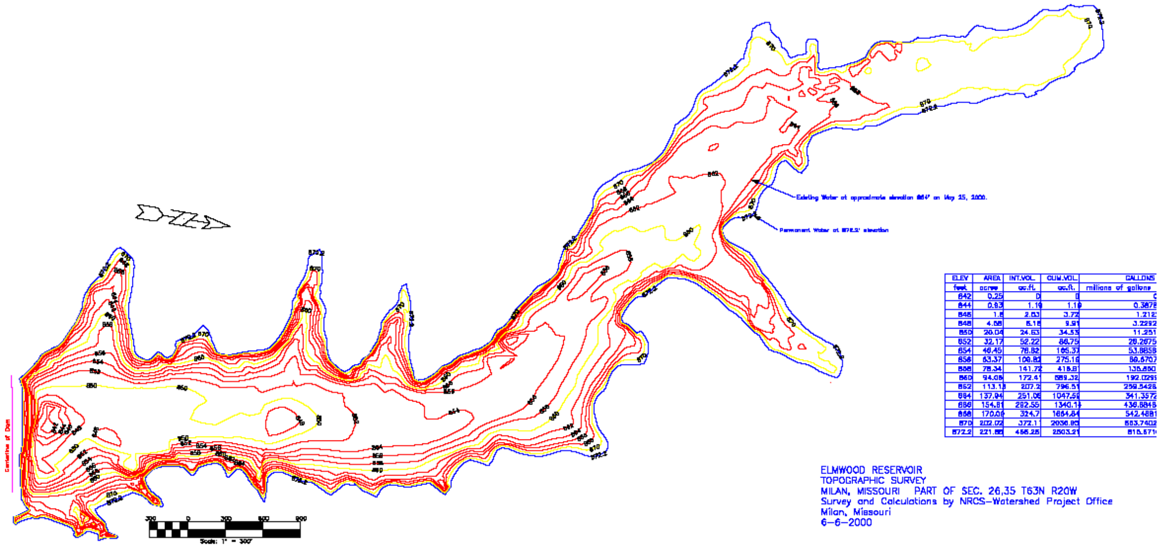
Total demand……………………………….1.65 million gallons per day………..5.06 acre-feet.

[OTHER]

The volume of water diverted from Locust creek into Elmwood Reservoir.

Determination of the volume of water available for pumping was made using daily discharges at the stream gage at Linneus. The drainage area at Linneus is 550 square miles and the drainage area at the point of pumping is 225 square miles. Daily discharge rates at the point of diversion were determined by a ratio of drainage areas. Pumping was only planned for flows above 10 cubic feet per second. Ten cubic feet per second allows for pumping plus in-stream flow needs. The maximum rate of pumping was 3000 gallons per minute or 6.68 cubic feet per second. It was necessary to have continuous pumping when Locust Creek carried sufficient flow.

Elmwood Reservoir

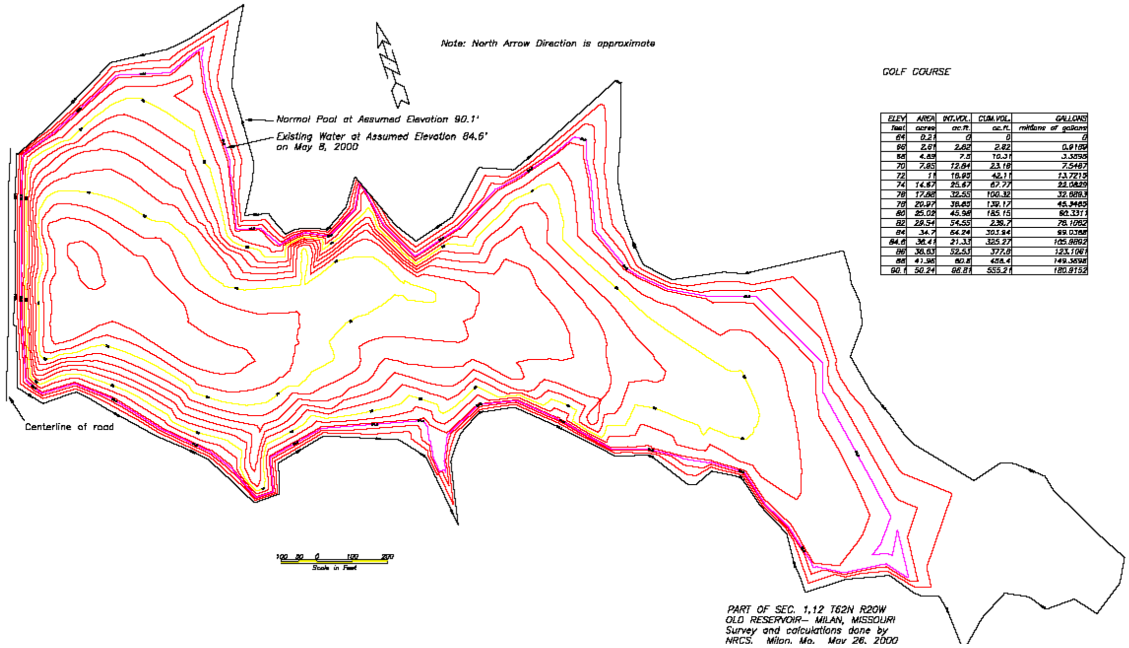


ELEV	AREA	INT.VOL.	CUM.VOL.	GALLONS
feet	acres	ac.ft.	ac.ft.	millions of gallons
842	0.25	0	0	0
844	0.83	1.19	1.19	0.3878
846	1.8	2.53	3.72	1.2122
848	4.58	6.18	9.91	3.2292
850	20.04	24.63	34.53	11.251
852	32.17	52.22	86.75	28.2675
854	46.45	78.62	165.37	53.8858
856	63.37	109.82	275.16	89.6707
858	78.34	141.72	416.81	135.850
860	94.08	172.41	589.32	192.0295
862	113.13	207.2	796.51	259.5428
864	137.94	251.06	1047.59	341.3572
866	154.81	292.55	1340.14	436.8846
868	170.08	324.7	1664.84	542.4881
870	202.02	372.11	2036.95	663.7402
872.2	221.86	466.26	2503.21	815.6714

Bathymetric map and area/volume table of Elmwood Reservoir, Milan, Missouri. ouri.

Figure 32.1.a

Golf Course Reservoir



ELEV	AREA	INT.VOL.	CUM.VOL.	GALLONS
feet	acres	ac.ft.	ac.ft.	millions of gallons
64	0.21	0	0	0
66	2.61	2.82	2.82	0.9189
68	4.89	7.5	10.31	3.3595
70	7.85	12.84	23.16	7.5467
72	11	16.95	42.11	13.7215
74	14.67	25.67	67.77	22.0829
76	17.88	32.55	100.32	32.6893
78	20.97	38.85	139.17	45.3485
80	25.02	45.98	185.15	60.3311
82	29.54	54.55	239.7	78.1082
84	34.7	64.24	303.94	99.0388
84.6	36.41	21.33	325.27	105.9892
86	38.63	52.53	377.8	123.1061
88	41.96	80.6	458.4	149.3698
90.1	50.24	96.81	555.21	180.9152

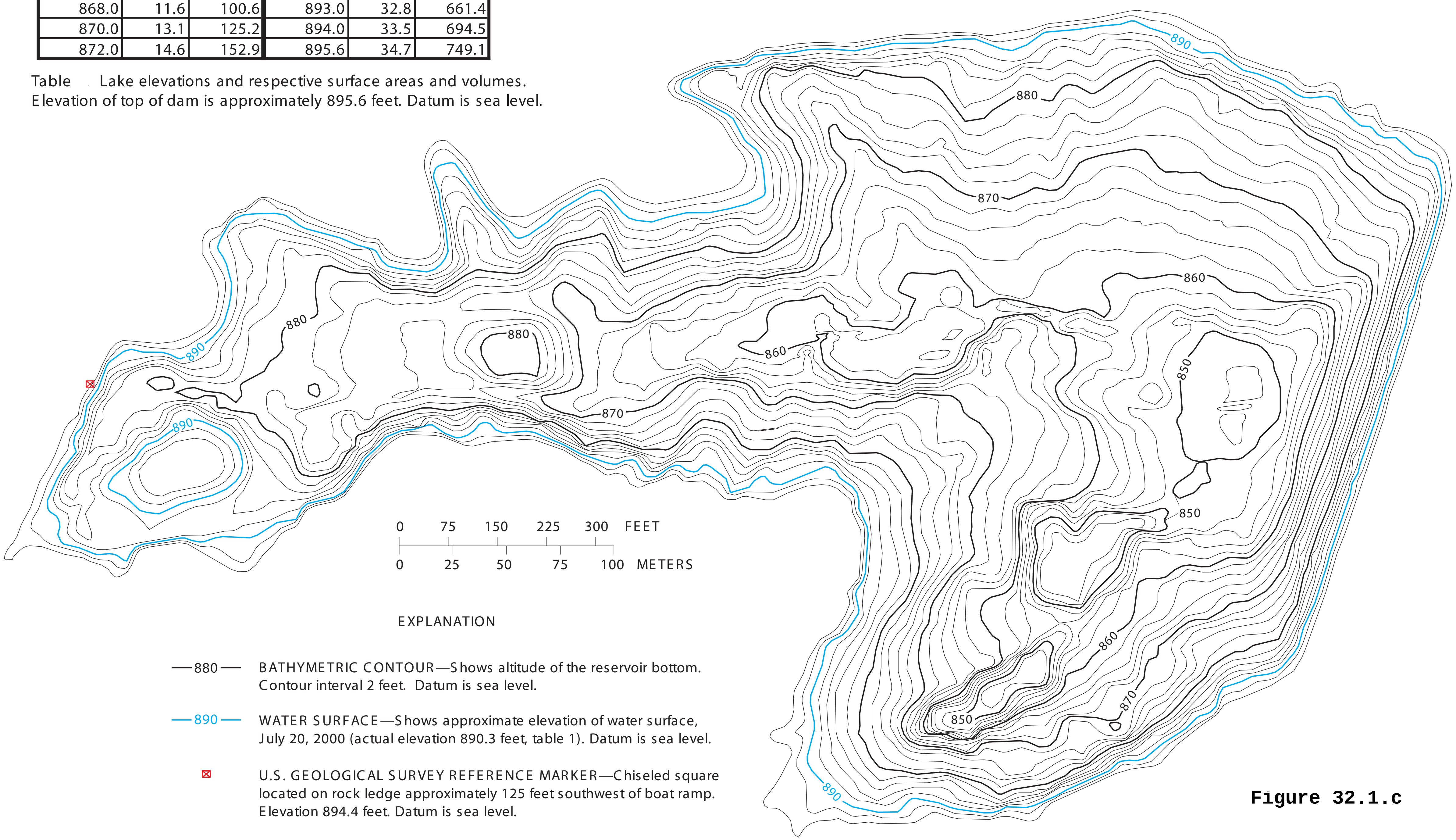
Bathymetric map and area/volume table of Golf Course Reservoir, Milan, Missouri.

Figure 32.1.b

Elevation (feet)	Area (acres)	Volume (acre-ft)	Elevation (feet)	Area (acres)	Volume (acre-ft)
846.0	0.2	0.2	874.0	16.4	183.8
848.0	0.5	0.7	876.0	18.6	218.8
850.0	1.2	2.4	878.0	20.6	258.0
852.0	1.9	5.5	880.0	22.4	300.9
854.0	2.6	10.0	882.0	24.2	347.5
856.0	3.2	15.8	884.0	25.8	397.5
858.0	4.3	23.3	886.0	27.3	450.6
860.0	5.4	33.0	888.0	29.0	506.9
862.0	6.9	45.3	890.0	30.5	566.4
864.0	8.4	60.5	890.3	30.8	575.6
866.0	10.0	78.9	892.0	32.0	629.0
868.0	11.6	100.6	893.0	32.8	661.4
870.0	13.1	125.2	894.0	33.5	694.5
872.0	14.6	152.9	895.6	34.7	749.1

Table   Lake elevations and respective surface areas and volumes.
Elevation of top of dam is approximately 895.6 feet. Datum is sea level.

SHATTO LAKE



EXPLANATION

—880— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

—890— WATER SURFACE—Shows approximate elevation of water surface, July 20, 2000 (actual elevation 890.3 feet, table 1). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on rock ledge approximately 125 feet southwest of boat ramp. Elevation 894.4 feet. Datum is sea level.

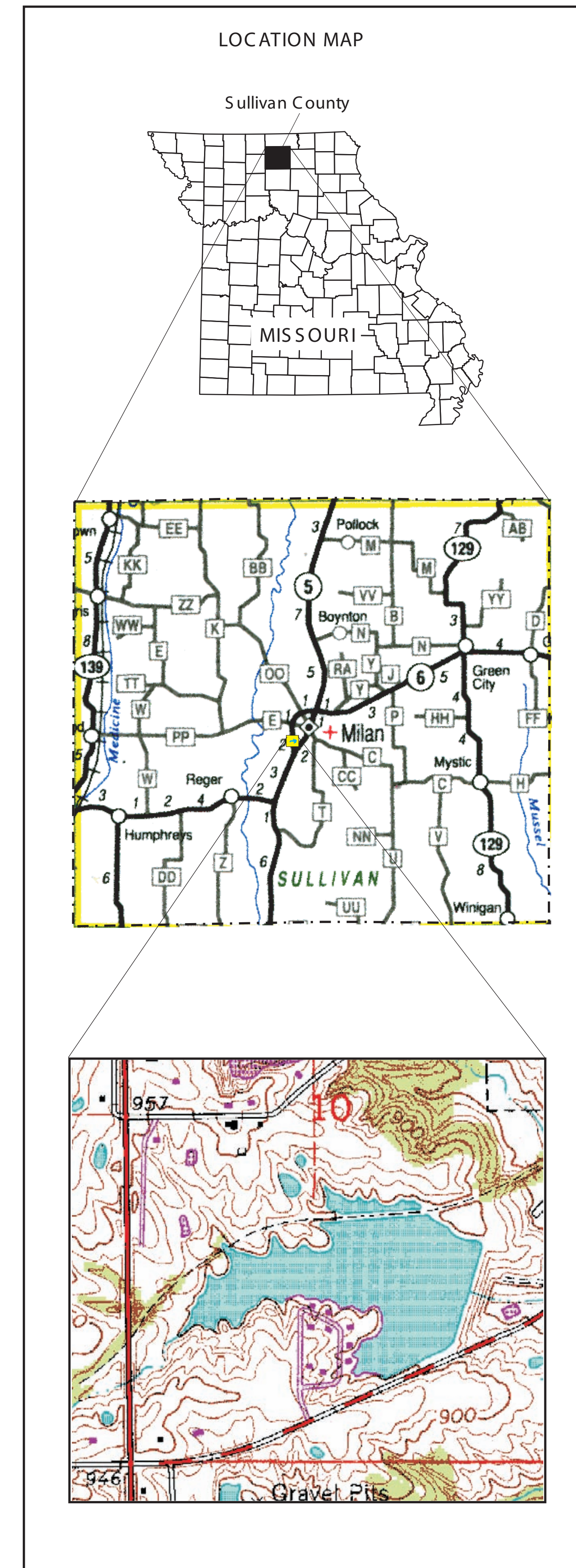


Figure 32.1.c

USGS
science for a changing world

Bathymetric map and area/volume table for Shatto Lake near Milan, Missouri.

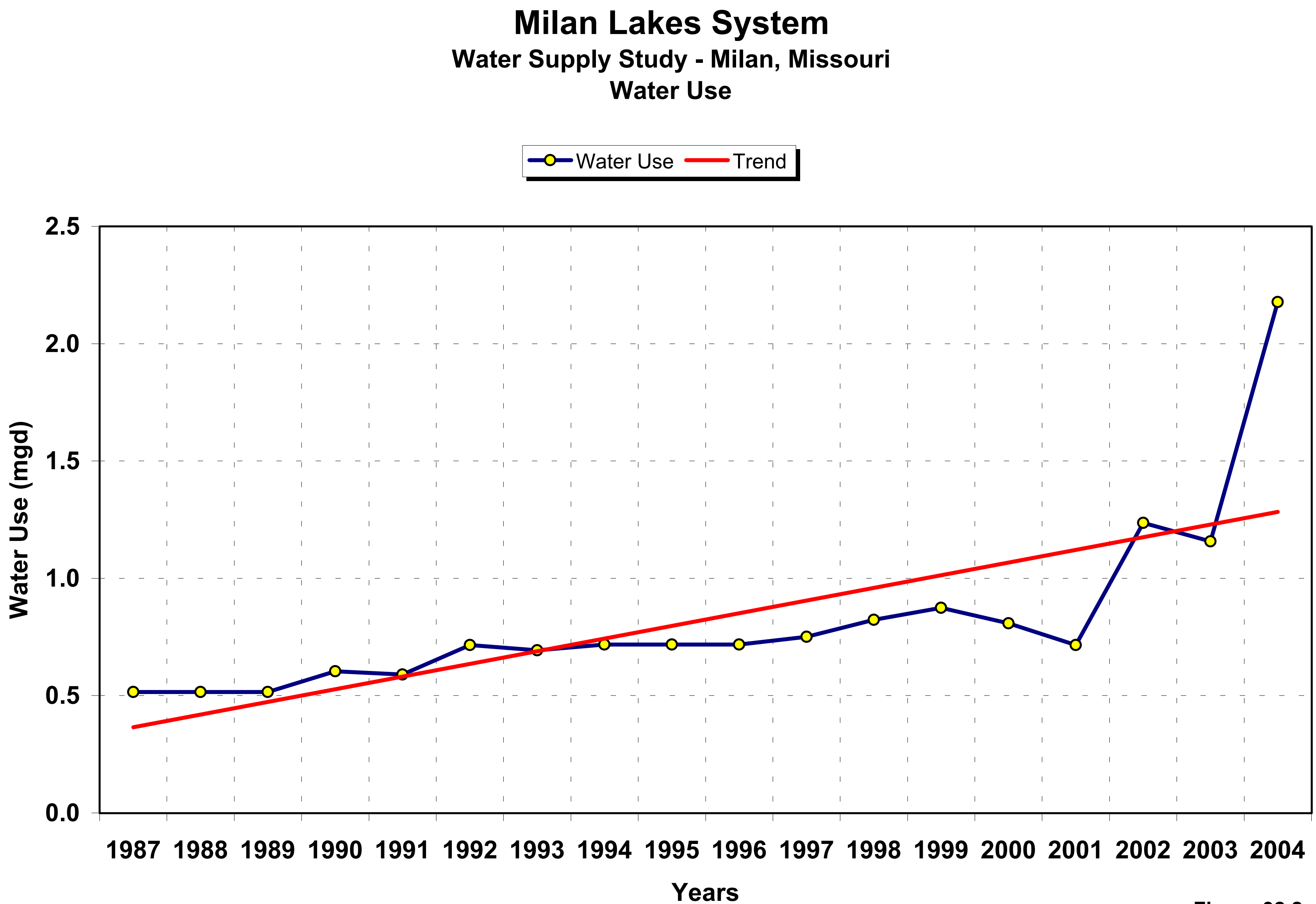

Milan Lakes System
Water Supply Study - Milan, Missouri
Water Use
Water Use
Trend
Water Use (mgd)
2.5
2.0
1.5
1.0
0.5
0.0
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Years

Figure 32.2

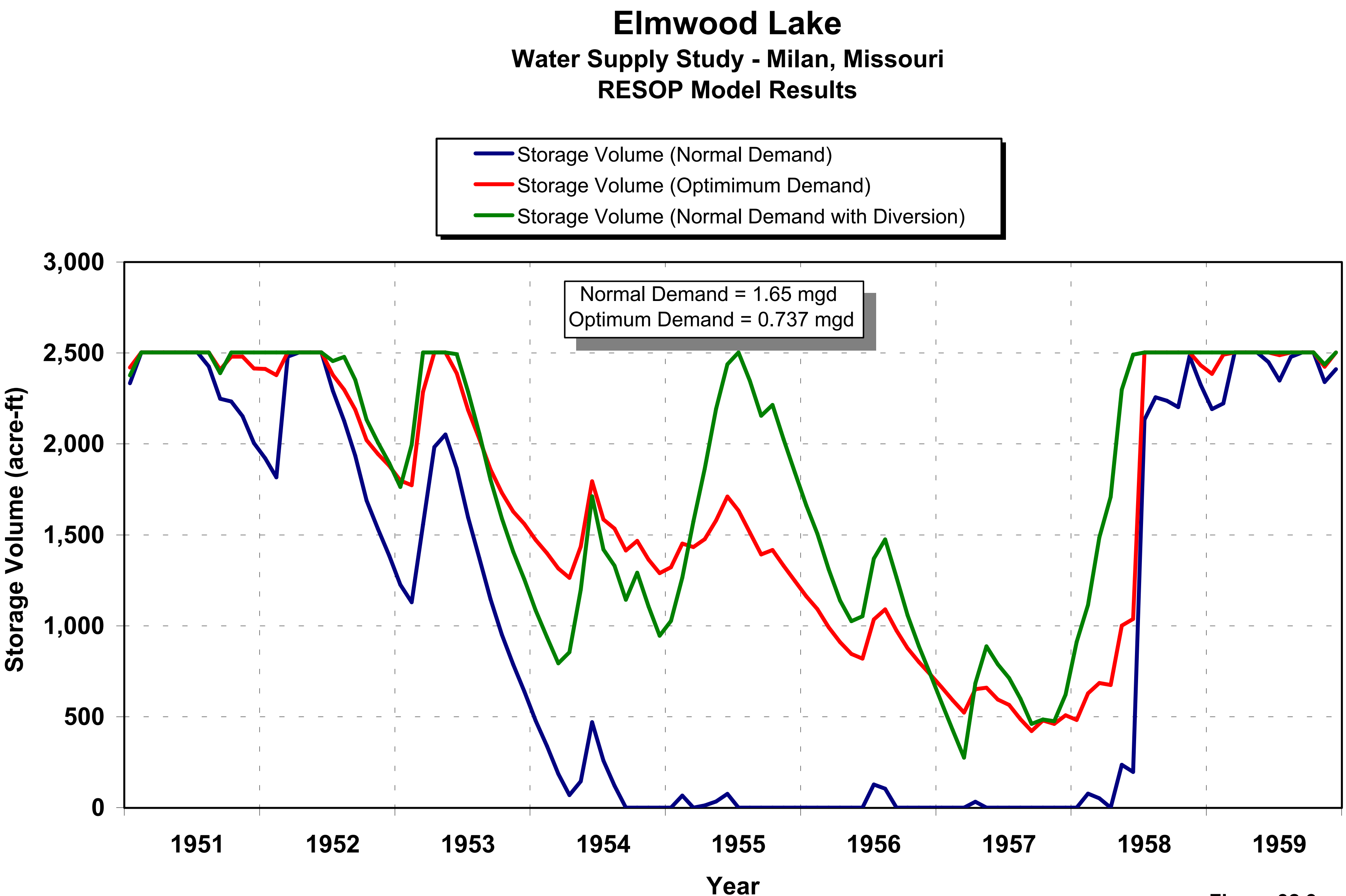

Elmwood Lake
Water Supply Study - Milan, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimimum Demand)
Storage Volume (Normal Demand with Diversion)
Normal Demand = 1.65 mgd
Optimum Demand = 0.737 mgd
Storage Volume (acre-ft)
3,000
2,500
2,000
1,500
1,000
500
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 32.3.a

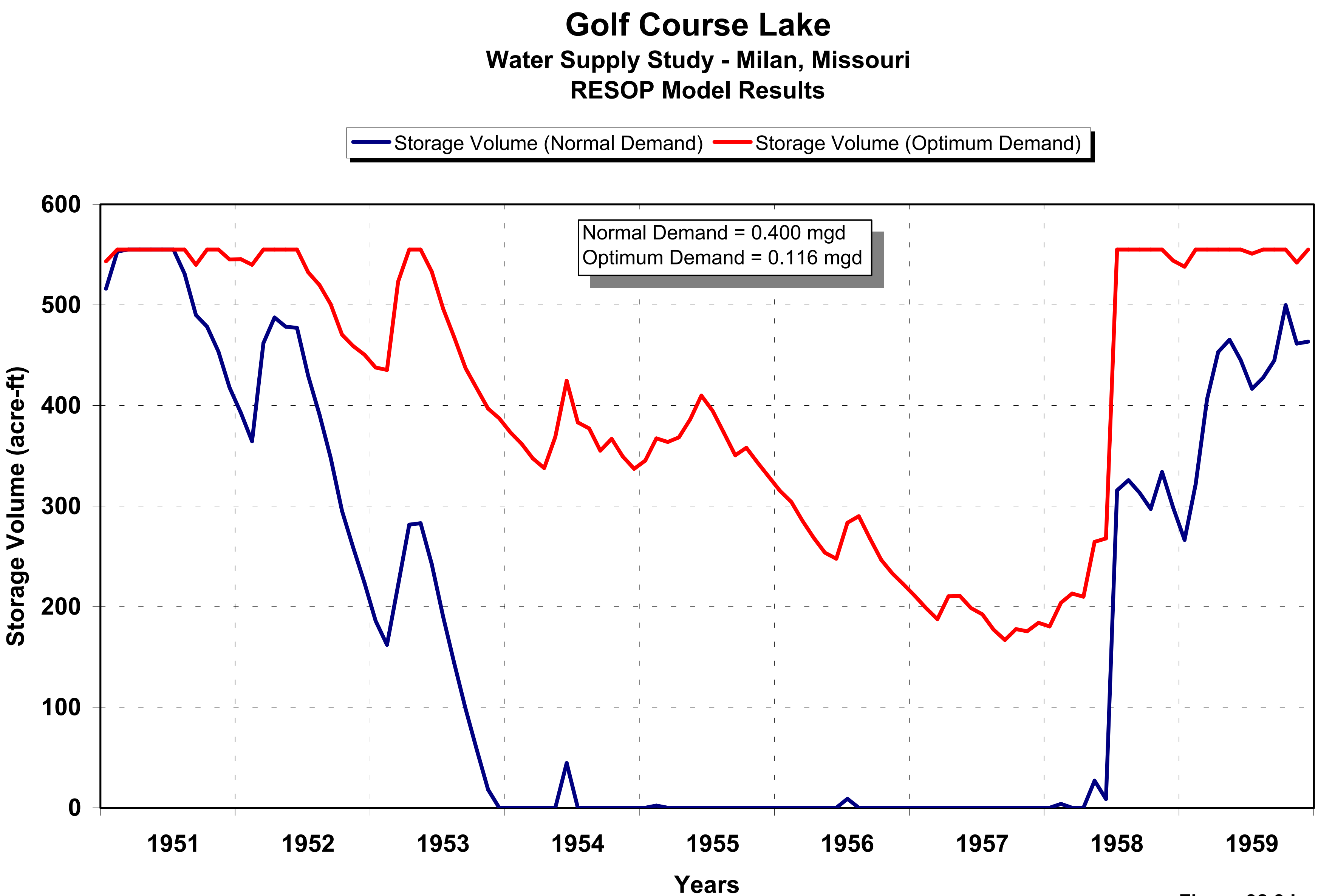

Golf Course Lake
Water Supply Study - Milan, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 0.400 mgd
Optimum Demand = 0.116 mgd
Storage Volume (acre-ft)
600
500
400
300
200
100
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 32.3.b

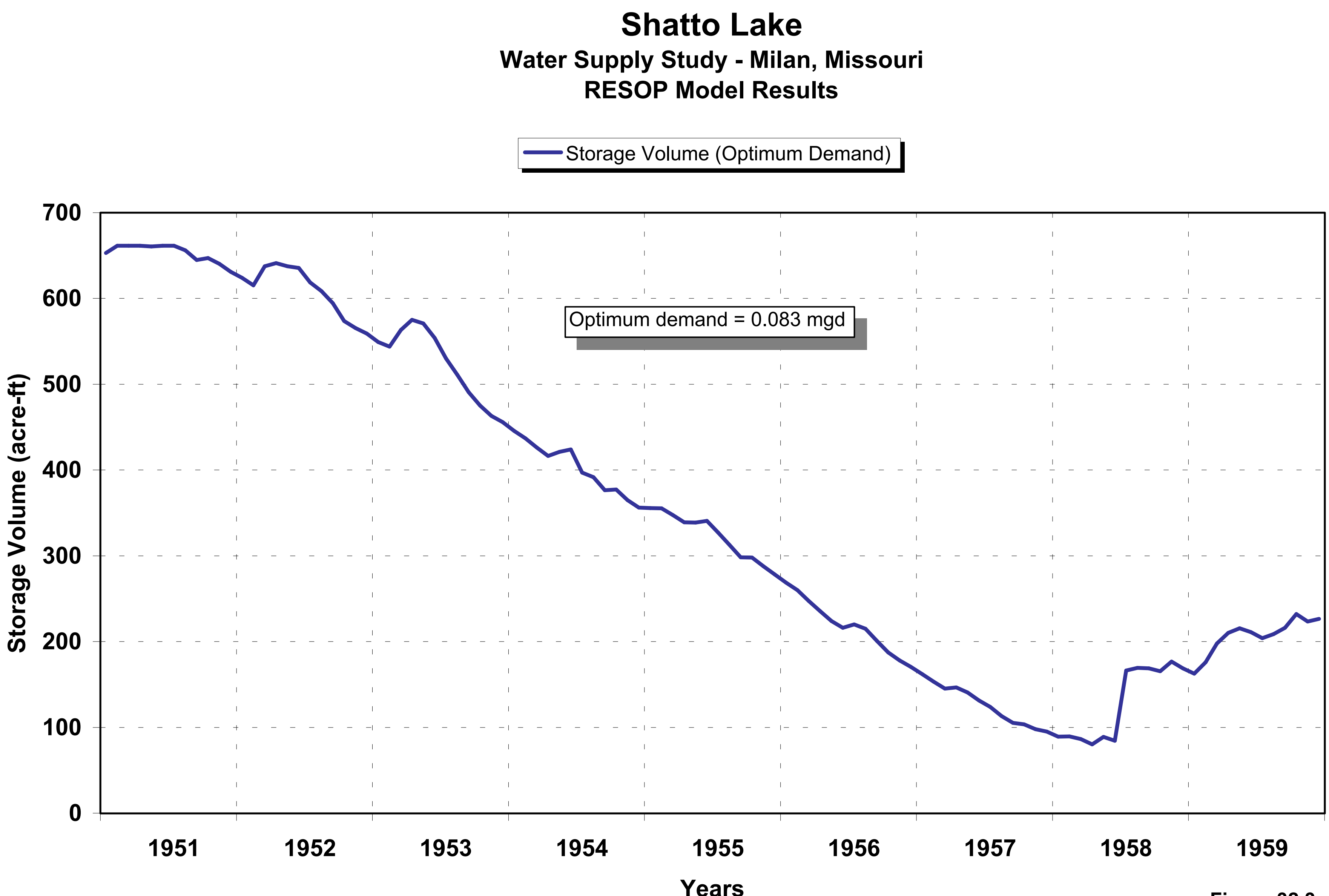

Shatto Lake
Water Supply Study - Milan, Missouri
RESOP Model Results
Storage Volume (Optimum Demand)
Optimum demand = 0.083 mgd
Storage Volume (acre-ft)
700
600
500
400
300
200
100
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 32.3.c

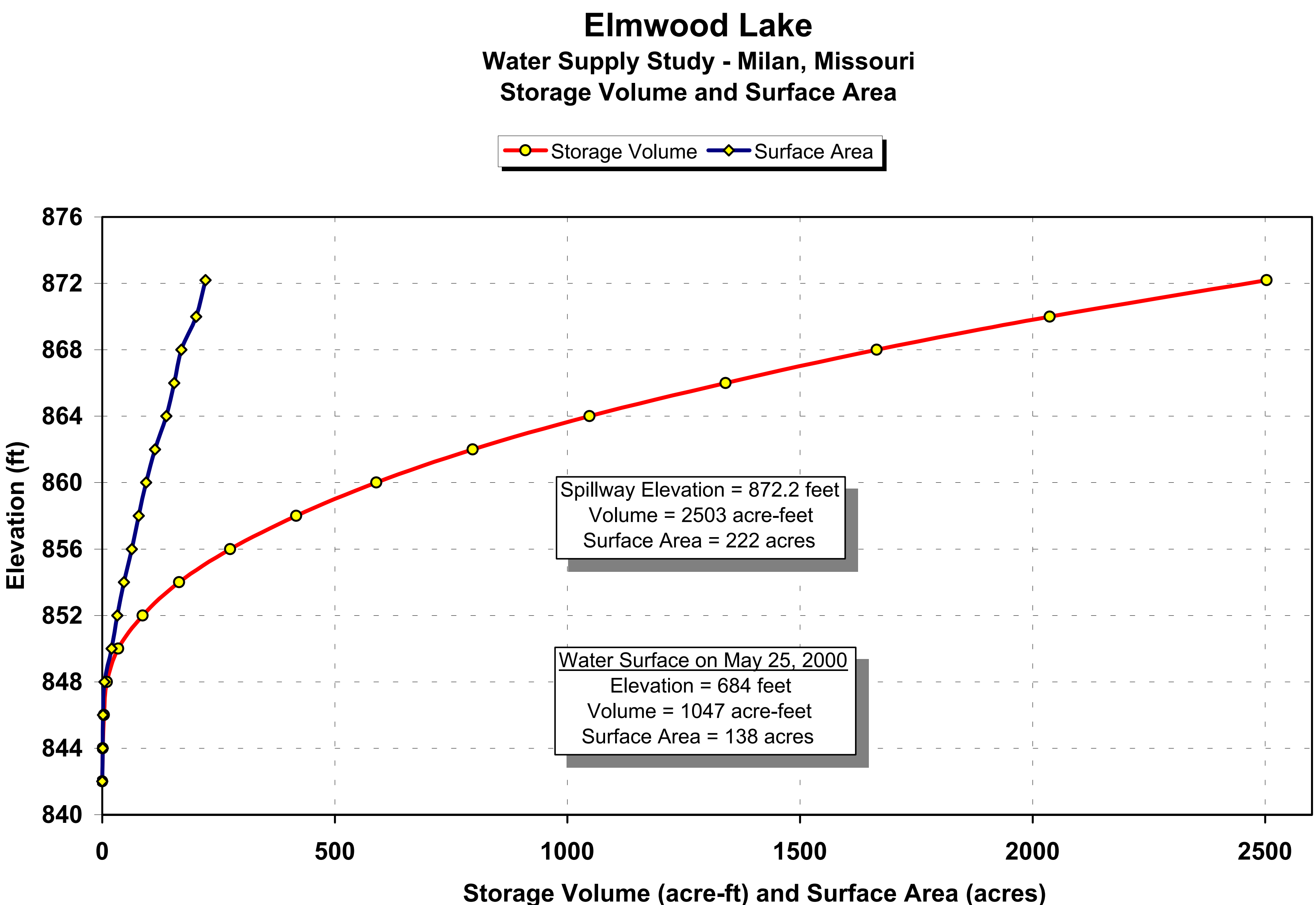

Elmwood Lake
Water Supply Study - Milan, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
876
872
868
864
860
856
852
848
844
840
Elevation (ft)
0
500
1000
1500
2000
2500
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 872.2 feet
Volume = 2503 acre-feet
Surface Area = 222 acres
Water Surface on May 25, 2000
Elevation = 684 feet
Volume = 1047 acre-feet
Surface Area = 138 acres

Figure 32.4.a

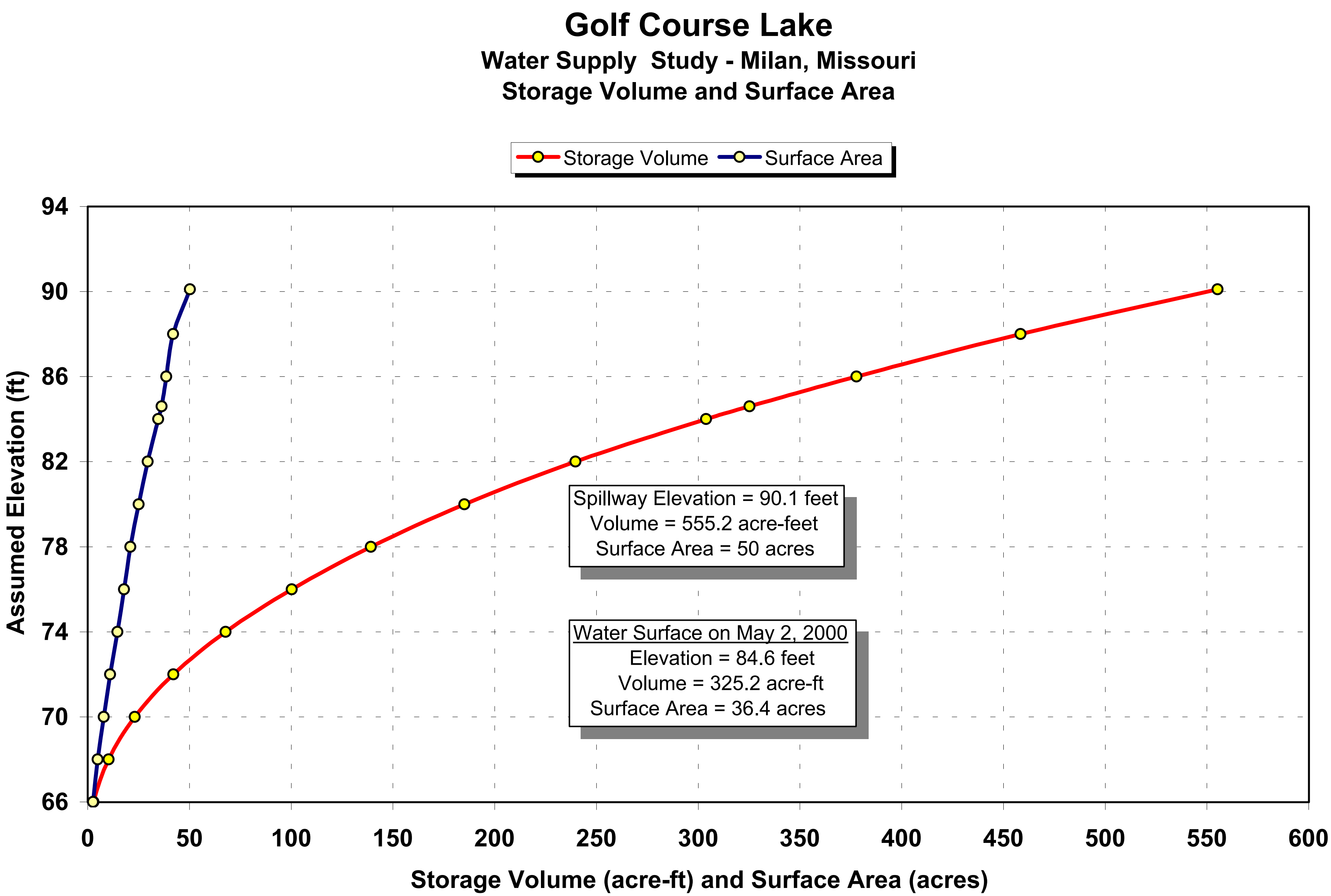

Golf Course Lake
Water Supply Study - Milan, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
94
90
86
82
78
74
70
66
Assumed Elevation (ft)
0
50
100
150
200
250
300
350
400
450
500
550
600
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 90.1 feet
Volume = 555.2 acre-feet
Surface Area = 50 acres
Water Surface on May 2, 2000
Elevation = 84.6 feet
Volume = 325.2 acre-ft
Surface Area = 36.4 acres

Figure 32.4.b

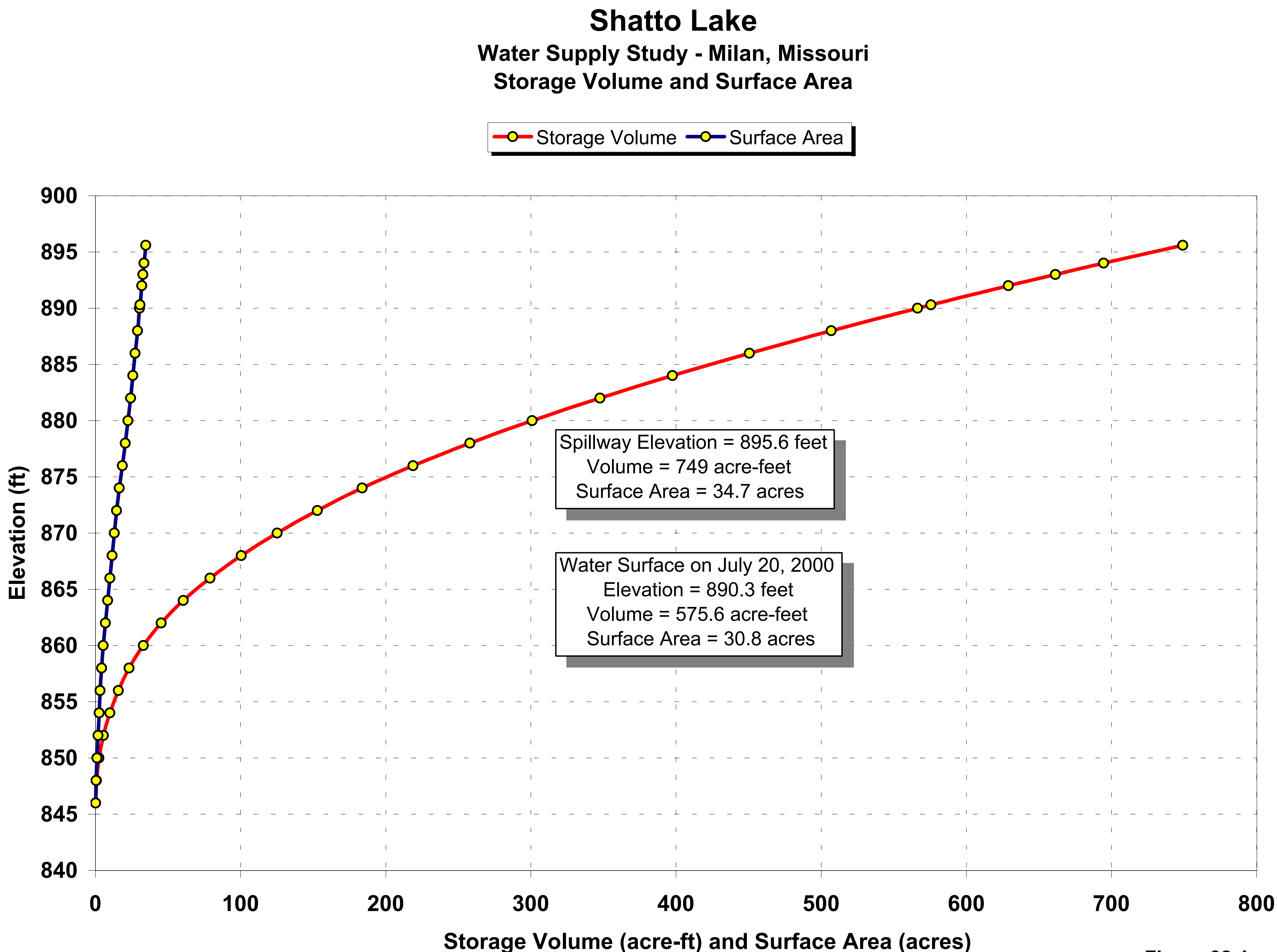

Shatto Lake
Water Supply Study - Milan, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 895.6 feet
Volume = 749 acre-feet
Surface Area = 34.7 acres
Water Surface on July 20, 2000
Elevation = 890.3 feet
Volume = 575.6 acre-feet
Surface Area = 30.8 acres
Elevation (ft)
900
895
890
885
880
875
870
865
860
855
850
845
840
0
100
200
300
400
500
600
700
800
Storage Volume (acre-ft) and Surface Area (acres)

Figure 32.4.c

Sugar Creek Reservoir
Water Supply Study – Moberly, Missouri
Drought Assessment Analysis

I. Overview

Sugar Creek Reservoir (figure 33.1) is located in Randolph County, Missouri, Approximately two miles north of the City of Moberly. Sugar Creek Reservoir is the primary source of water for the City of Moberly. In the past, Moberly has sold finished water to a public Water Supply district but because of shortages during periods of drought, the water district and non-municipal demands were removed from the system in 1992. The Sugar Creek Reservoir serves a population of approximately 13,741 with an estimated water demand of 1.44 million gallons per day (figure 33.2) according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

Sugar Creek Reservoir has a drainage area of 11.05 square miles and is located on Sugar Creek, a tributary to East Fork Chariton River. The reservoir would be unable to supply the normal 2001 demand of 1.54 million gallons per day. The reservoir would be empty from 1956 through 1958. The optimum yield the lake is able to produce with no additional water being added to the system is 1.20 million gallons per day (figure 33.3). By diverting water into Sugar Creek Reservoir from East Fork Chariton River at a rate of 800 gallons per minute, the demand of 1.54 million gallons per day could be met. When flow in East Fork Chariton River is not sufficient for diversion, the city would be able to purchase water from Long Branch Reservoir at Macon. Water can be released from Long Branch Reservoir and allowed to flow downstream to the pump intake near Moberly. Moberly has been reporting East Fork Chariton River as a supply source beginning in 1992.

The volume of water that would be required by pumping from East Fork Chariton River:

1954…………………………………….. 317.3 million gallons
1955…………………………………….. 421.3 million gallons
1956……………………………………… 421.3 million gallons
1957…………………………………….. 421.3 million gallons
1958…………………………………….. 208.5 million gallons

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Two scenarios were analyzed for the Sugar Creek reservoir system using the RESOP model:

1. The first scenario assesses the water budget for the reservoir with no additional sources of water (no diversion from the East Fork Chariton River). An analysis of ‘Normal’ demand (actual demand from 2001) was applied to the reservoir during the drought of record to assess potential water deficits. A second analysis for ‘Optimum’ demand was performed to determine the firm yield from the reservoir without additional water sources - this value represents the viable quantity of water available. Figure 33.3 illustrates the relationship between these two analysis - when actual demand is applied to this scenario the reservoir is completely emptied and would not be capable of supplying water to meet demand. The optimum yield is insufficient to meet demand.

2. The second scenario analyzes ‘Normal’ demand for the Sugar Creek Reservoir system when additional water is pumped to the reservoir from the East Fork Chariton River (figure 33.3). Based on this analysis, it was estimated that water diverted from the East Fork Chariton

River to the reservoir would allow Moberly to meet the 2001 demand of 1.537 million gallons per day. It would be necessary to pump 800 gallons per minute continuously from March 1954 through March 1958.

II. Drought Assessment Summary

The Sugar Creek Reservoir system without additional sources of water is not sufficient to meet demand. The 2001 demand of 1.537 million gallons per day, when applied to the reservoir during the drought of record (with no other sources of water) would have resulted in water deficits January 1956 through June 1958. The estimated optimum yield from the Sugar Creek Reservoir system without supplementary supplies is 1.2 million gallons per day (figure 33.3).

The Sugar Creek Reservoir system is capable of meeting and exceeding the 2001 demand of 1.537 million gallons per day with additional water diverted to the reservoir from the East Fork Chariton River. The 2001 demand of 1.537 million gallons per day can be met if water is diverted from the river, averaging 800 gallons per minute continuously when the lake level falls below elevation 736 feet (2500 acre-feet remaining in the reservoir) from March 1956 through March 1958. The optimum yield is 1.200 million gallons per day.

III. RESOP Model Parameters

Terms in brackets refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Sugar Creek Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources December 15-18 and 30-31, 2003. Surface area of the lake and associated storage volume capacity are illustrated in figure 33.4.

Sugar Creek Lake Physical Data

Sugar Creek Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional Notes
716	0.1	0.01	
718	11.9	8.1	
720	39.1	55.4	
722	68.7	163	
724	93.8	328	
726	117	539	
728	141	797	
730	164	1,100	
732	188	1,460	
734	214	1,860	
736	230	2,300	
738	245	2,780	
740	259	3,280	
742	279	3,820	
744	297	4,400	
746	314	5,010	
746.8	320	5,250	Spillway Elevation
746.9	332	5,290	Mean Lake Conditions December 15-18, 2003

[LIMITS]

Maximum storage………………………………………………………………. 5250 acre-feet.
Minimum storage……………………………………………………………….330 acre-feet.
Drainage basin Size…………………………………………………………11.05 square miles.

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Sugar Creek Lake is approximately 3.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation rates from Moberly, Missouri were used for this analysis.

Average annual rainfall for the period 1951 through 2002 is 37.8 inches. Annual rainfall for 1953 through 1957 is 24.9, 34.8, 37.7, 27.9, and 34.0 inches.

[RUNOFF]

Regional monthly runoff values were determined from stream gauge data. A monthly runoff volume in watershed inches was determined from data collected at the Moniteau Creek gauge near Fayette, Missouri. Another gauge on Elk Fork Salt River (near Paris, Missouri) was also comparatively analyzed. Measurements recorded at the lake were similar to those observed at the two gauges. For this analysis, regional runoff was determined at the Moniteau Creek drainage basin. Both drainages rise in the Moberly area and have soil types and topography similar to that of Sugar Creek drainage basin. Results were similar and because Moniteau Creek gauge has the most complete data, it was used to represent Sugar Creek drainage basin. For months where precipitation values appeared inconsistent with measured runoff values, daily rainfall values were considered. Antecedent moisture was estimated for each rainfall event and adjustments to the Natural Resource Conservation Service (NRCS) runoff curve number were made to estimate runoff for each storm event. (See Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Sugar Creek Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

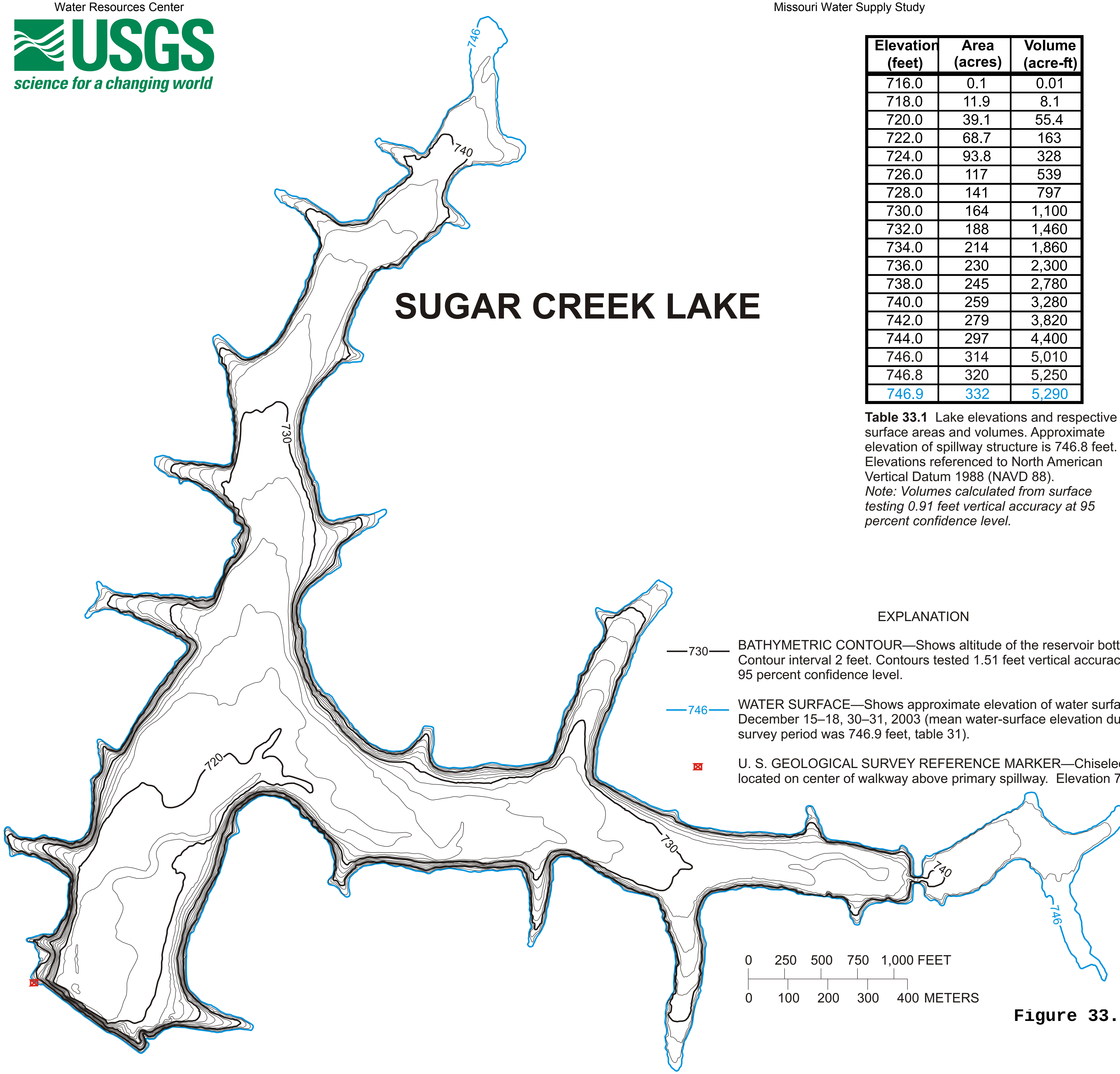
[DEMAND]

Water demand for this analysis, 2001 demand of 1.537 million gallons per day was used.

Values for water usage by Moberly are illustrated in figure 33.2. Between 1987 and 2001, water demand in Moberly is increasing at 4 percent per year. Optimum demand (yield) from Sugar Creek Reservoir without an additional source of water (pumping from the East Fork Chariton River) is 1.200 million gallons per day.

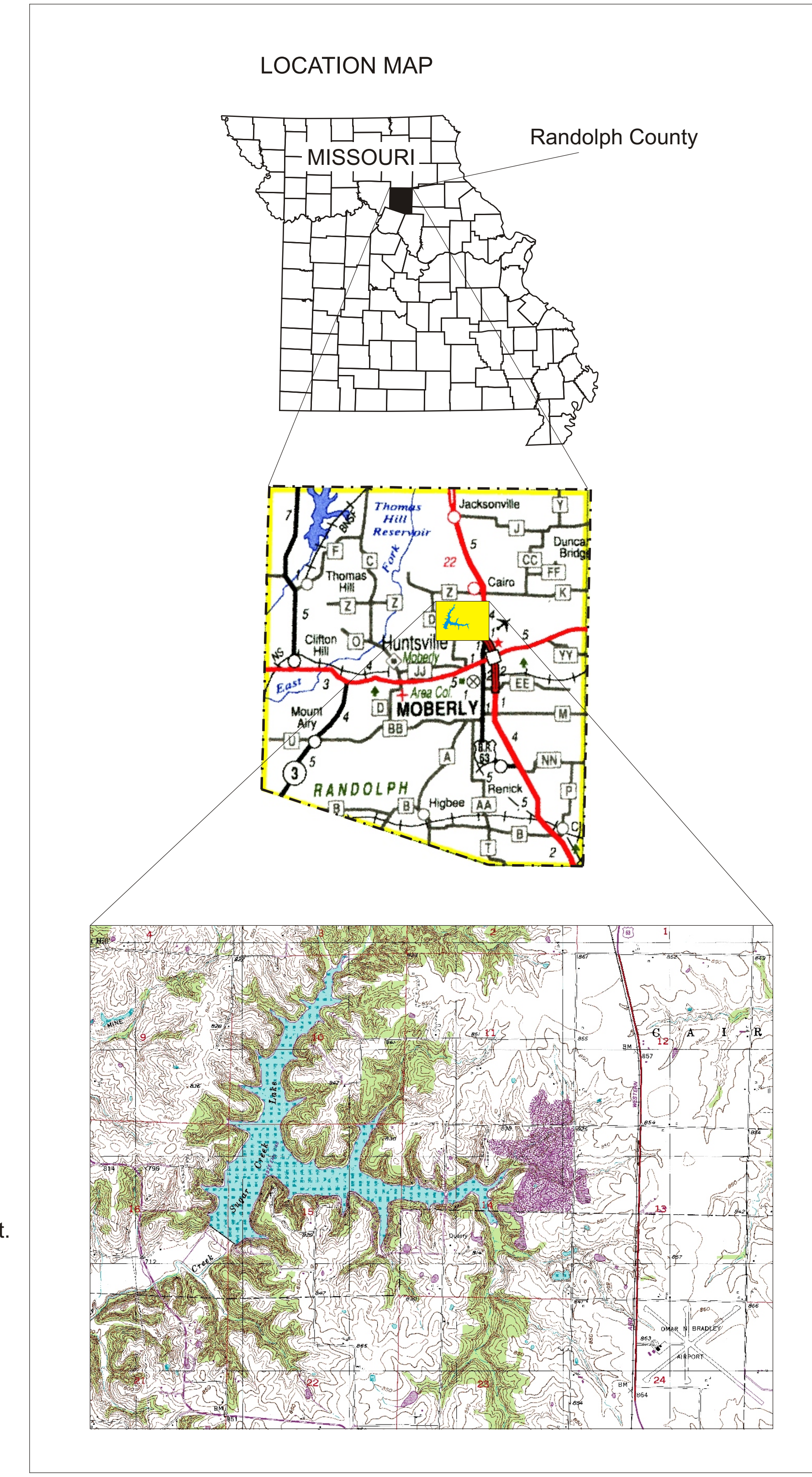
[OTHER]

For this evaluation the pumps were run full time pumping 800 gallons per minute continuously from March 1954 to March 1958 from East Fork Chariton River. When the stream did not have enough flow would be released from Long Branch Reservoir at Macon to allow pumping from the stream.



Elevation (feet)	Area (acres)	Volume (acre-ft)
716.0	0.1	0.01
718.0	11.9	8.1
720.0	39.1	55.4
722.0	68.7	163
724.0	93.8	328
726.0	117	539
728.0	141	797
730.0	164	1,100
732.0	188	1,460
734.0	214	1,860
736.0	230	2,300
738.0	245	2,780
740.0	259	3,280
742.0	279	3,820
744.0	297	4,400
746.0	314	5,010
746.8	320	5,250
746.9	332	5,290

Table 33.1 Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 746.8 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 0.91 feet vertical accuracy at 95 percent confidence level.



EXPLANATION

—730— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Contours tested 1.51 feet vertical accuracy at 95 percent confidence level.

—746— WATER SURFACE—Shows approximate elevation of water surface, December 15–18, 30–31, 2003 (mean water-surface elevation during survey period was 746.9 feet, table 31).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on center of walkway above primary spillway. Elevation 755.1 feet.

Figure 33.1

In cooperation with Missouri Department of Natural Resources

Figure 33.1 Bathymetric map and table of areas/volumes of the Sugar Creek Lake near Moberly, Missouri.

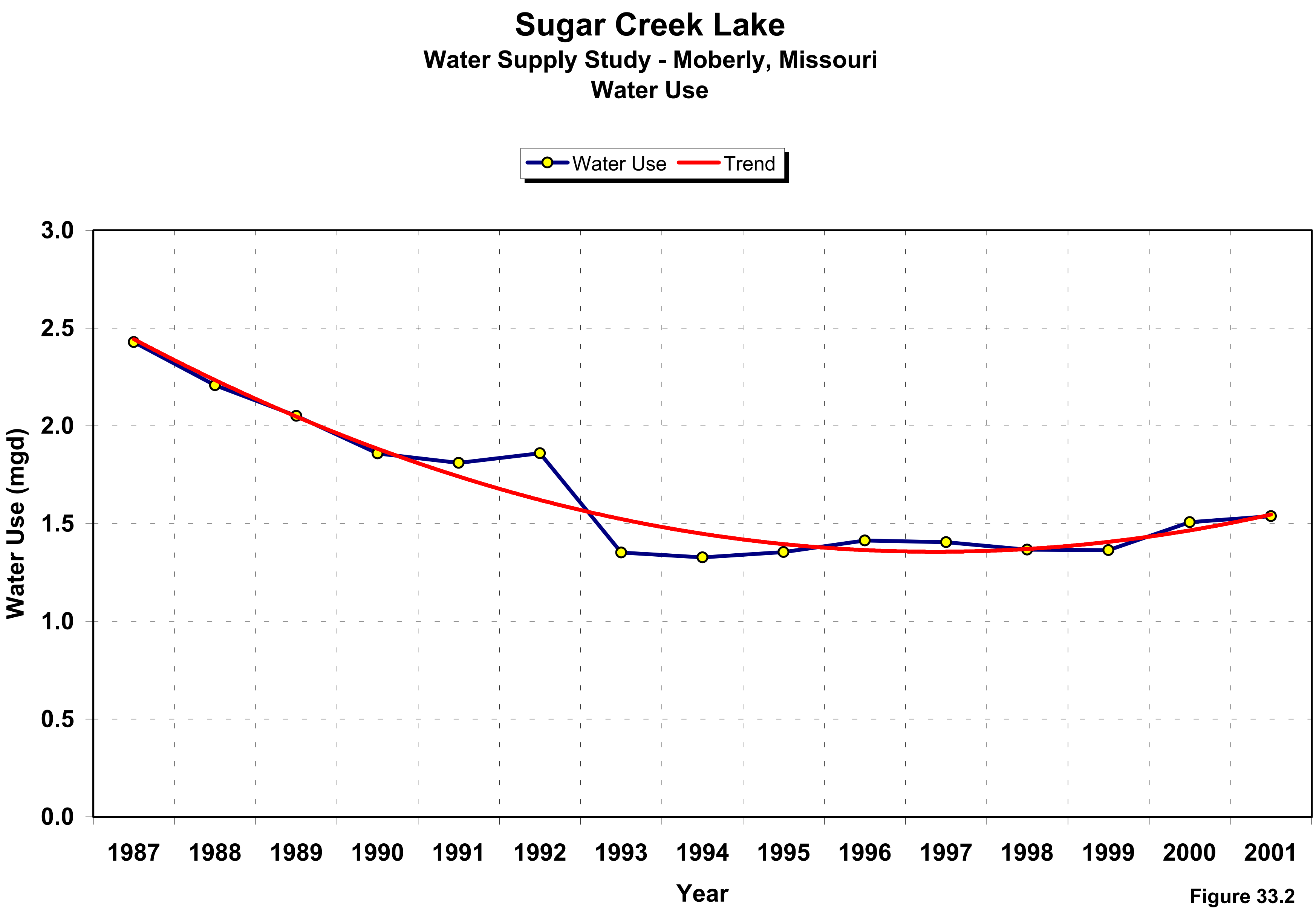

Sugar Creek Lake
Water Supply Study - Moberly, Missouri
Water Use
Water Use
Trend
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Water Use (mgd)
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 33.2

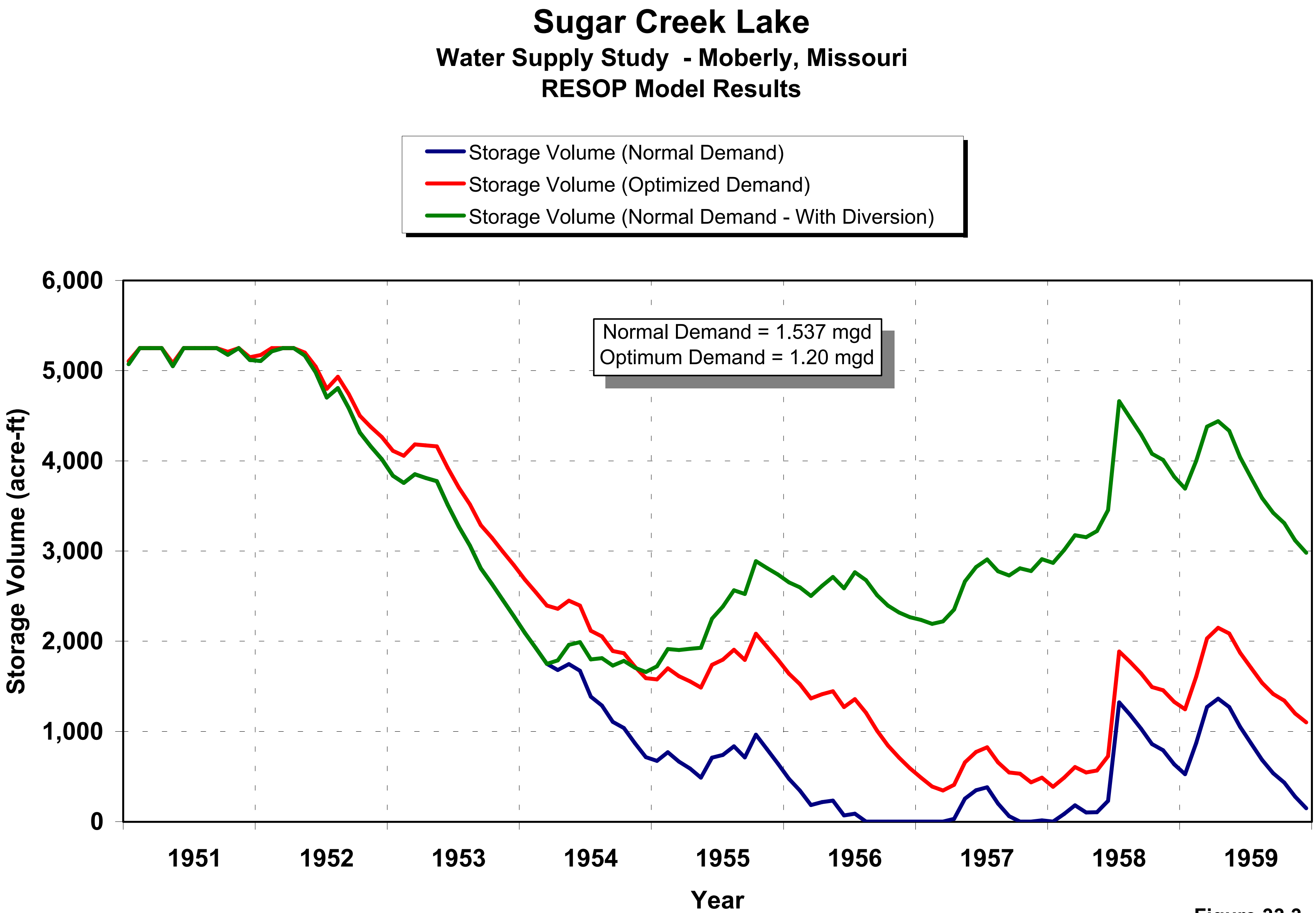

Sugar Creek Lake
Water Supply Study - Moberly, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimized Demand)
Storage Volume (Normal Demand - With Diversion)
Normal Demand = 1.537 mgd
Optimum Demand = 1.20 mgd
Storage Volume (acre-ft)
6,000
5,000
4,000
3,000
2,000
1,000
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 33.3

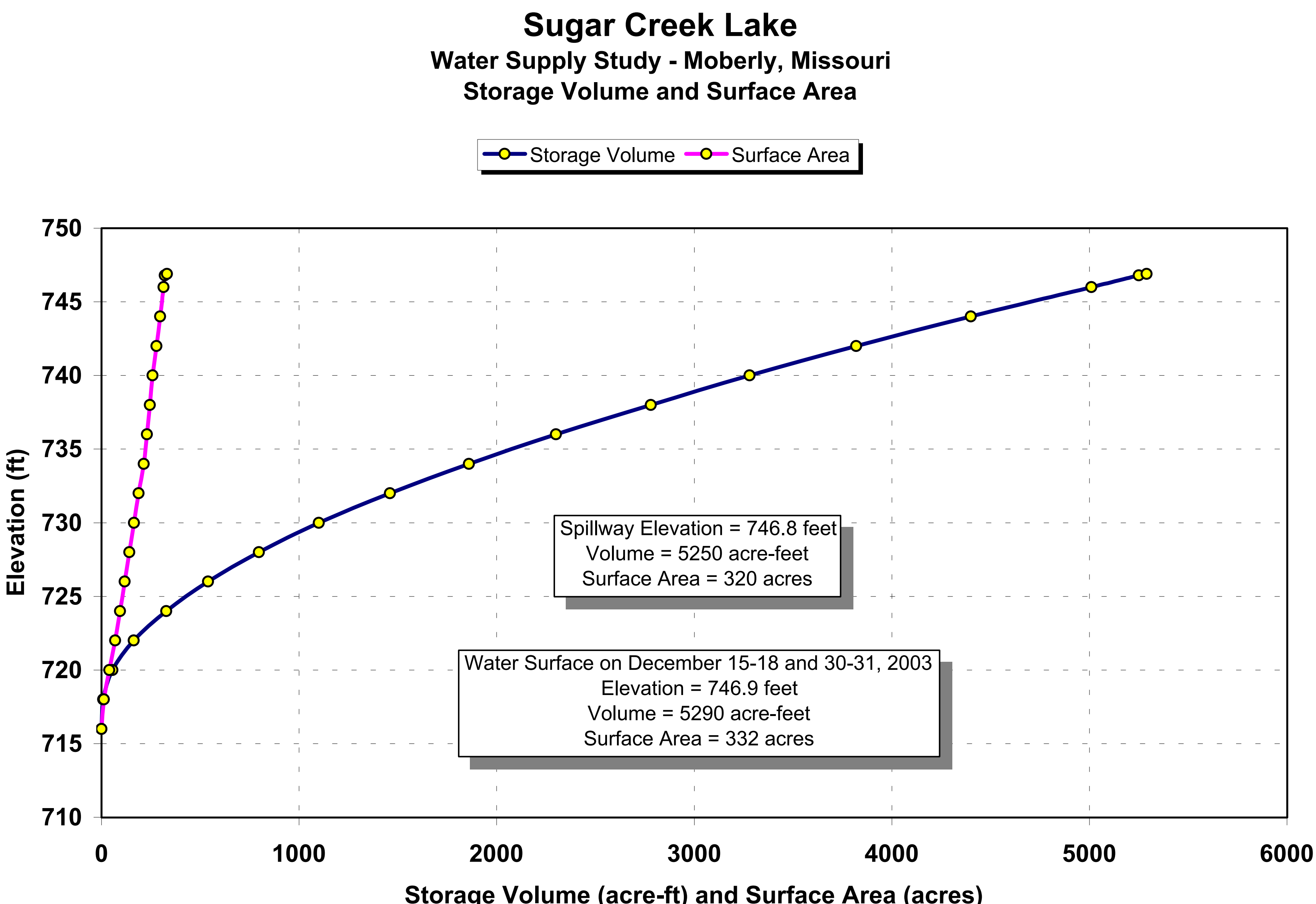

Sugar Creek Lake
Water Supply Study - Moberly, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Elevation (ft)
750
745
740
735
730
725
720
715
710
0
1000
2000
3000
4000
5000
6000
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 746.8 feet
Volume = 5250 acre-feet
Surface Area = 320 acres
Water Surface on December 15-18 and 30-31, 2003
Elevation = 746.9 feet
Volume = 5290 acre-feet
Surface Area = 332 acres

Figure 33.4

Route “J” Lake
Water Supply Study - Monroe City, Missouri
Drought Assessment Analysis

I. Overview

Route “J” Reservoir (figure 34.1) is located 4.5 miles southeast of Monroe City in western Ralls County, Missouri. The drainage area is 8.20 square miles. Monroe City water supply comes from the city owned lake on Route "J" and may be supplemented by South Lake, a smaller city lake. South Lake was not surveyed. The South Reservoir was not considered part of this analysis. Monroe City is located in the extreme northeast corner of Monroe County, Missouri. The Route “J” Reservoir serves a population of approximately 2,700 with an estimated water demand of 0.40 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). Monroe City sells finished water to Marion County Public Water Supply District #1.

Monroe City reported using 0.418 million gallons per day in 2001, based on Year 2001 total use of 152,701,000 gallons (figure 34.2). There has been significant fluctuation in water use with a high in 1991 of 1.03 million gallons per day then in 1993 demand was 0.315 and later in 1997 they used 0.785 million gallons per day. A rural water district transferred to an another source of water, which reduced the 1997 demand from 785,000 gallons per day to 418,000 gallons per day in 1999.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Route “J” Reservoir. Although an additional water supply lake, South Lake, can be used to supplement Monroe City’s water supply, the contribution of this reservoir to available supplies was not considered within the context of this model. The model assumes that ‘Normal’ demand for Monroe City is 0.418 million gallons per day and that ‘Optimum’ demand from the lake is 1.01 million gallons per day. Figure 34.3 illustrates these relationships.

II. Drought Assessment Summary

The Route “J” Reservoir is capable of meeting and exceeding the 2001 demand of 0.418 million gallons of water per day. The 2001 demand, when applied to the Route “J” Reservoir during the drought of record would have resulted in ample water supplies with 750 acre-feet of water remaining in the reservoir. Optimum yield for the lake is 1.01 million gallons per day. This analysis shows the Route "J" Reservoir capable of supplying approximately 2.4 times the 2001 demand.

III. RESOP Model Parameters

Terms in brackets refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Route “J” Reservoir (figure 34.1) conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on June 5, 2002. These relationships are illustrated in figure 34.4.

Route “J” Lake Physical Data

Route “J” Reservoir			
Elevation (feet)	Area (acres	Volume (acre-feet)	Additional Notes
638	0.10	0.05	
640	1.00	1.04	
642	4.04	5.47	
644	9.01	18.43	
646	14.40	41.84	
648	19.31	75.44	
650	25.18	119.85	
652	30.99	175.79	
654	37.13	243.87	
656	43.46	324.36	
658	50.13	417.99	
660	56.71	524.80	
662	63.70	645.33	
664	70.71	779.52	
666	79.82	929.37	
668	88.37	1,097.86	
669.3	94.90	1,216.31	Lake Conditions June 5, 2002
669.6	99.45	1,245.56	Spillway

[LIMITS]

Maximum storage ....1,245 acre-feet
Minimum storage ....30 acre-feet
Drainage basin size……………………………………………………….. 8.2 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from the primary lake was estimated to be 2.5 inches per month when the reservoir is at or near full capacity and 0.0 inches per month as the water level approaches the lower limits of the pool. The earthen dam on the Route “J” Reservoir is composed primarily of clay-rich materials and seepage through the dam is minimal.

[RAINFALL]

Precipitation rates from Monroe City, Missouri were used for this analysis.

Average annual rainfall at the Monroe City rain gauge for the latest 30 years of record is 40.49 inches. Annual rainfall for 1953 through 1957 is 28.38, 34.63, 38.45, 27.23, and 45.13 inches.

[RUNOFF]

Runoff values from North Fork Salt River were used for this analysis.

Regional monthly runoff values were determined from stream gauge data. A monthly runoff volume in watershed inches was determined from data collected at the North Fork Salt River gauge near Shelbina, Missouri. Another gauge on Salt River (near Bethel, Missouri) was also comparatively analyzed. Measurements recorded at the two gauges were similar. For months where precipitation values appeared inconsistent with measured runoff values, daily rainfall values were considered. Antecedent moisture was estimated for each rainfall event and adjustments to the Natural Resource Conservation Service (NRCS) runoff curve number were made to estimate runoff for each storm event. (See Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Route “J” Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

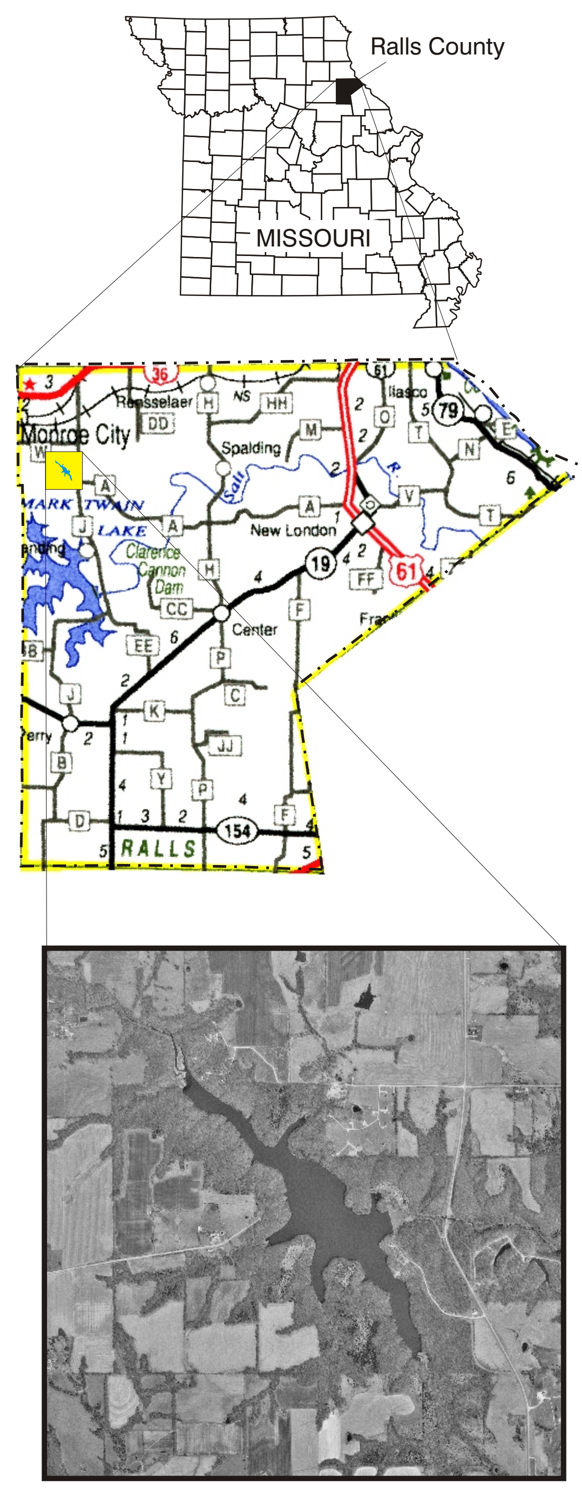
Values for water usage by Monroe City are illustrated in figure 34.2. Water demand in Monroe City has been inconstant each year varying from 3.03 million gallons per day in 1991 to a low of 0.315 million gallons per day in 1993. For this study 0.418 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

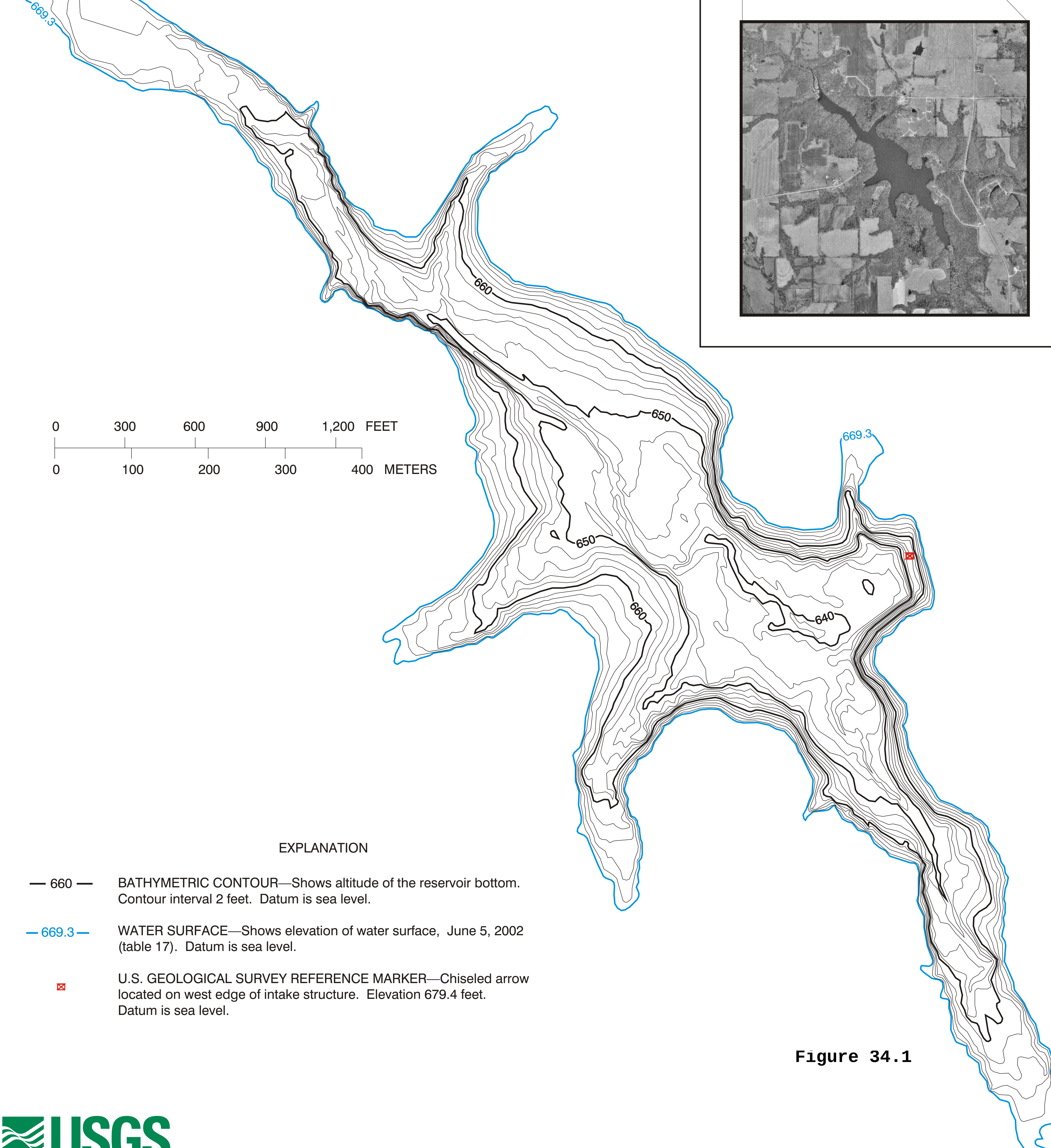
MONROE CITY LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
638.0	0.1	0.0
640.0	1.0	1.0
642.0	4.0	5.5
644.0	9.0	18.4
646.0	14.4	41.8
648.0	19.3	75.4
650.0	25.2	119.9
652.0	31.0	175.8
654.0	37.1	243.9
656.0	43.5	324.4
658.0	50.1	418.0
660.0	56.7	524.8
662.0	63.7	645.3
664.0	70.7	779.5
666.0	79.8	929.4
668.0	88.4	1,097.9
669.3	94.9	1,216.3
669.6	99.5	1,245.7

Table Lake elevations and respective areas and volumes. Spillway elevation is 669.6 ft. Datum is sea Level.

LOCATION MAP





0 300 600 900 1,200 FEET
0 100 200 300 400 METERS

EXPLANATION

— 660 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

— 669.3 — WATER SURFACE—Shows elevation of water surface, June 5, 2002 (table 17). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west edge of intake structure. Elevation 679.4 feet. Datum is sea level.

Figure 34.1

USGS
science for a changing world

Bathymetric map and table of areas/volumes of the Monroe City Lake near Monroe City, Missouri.

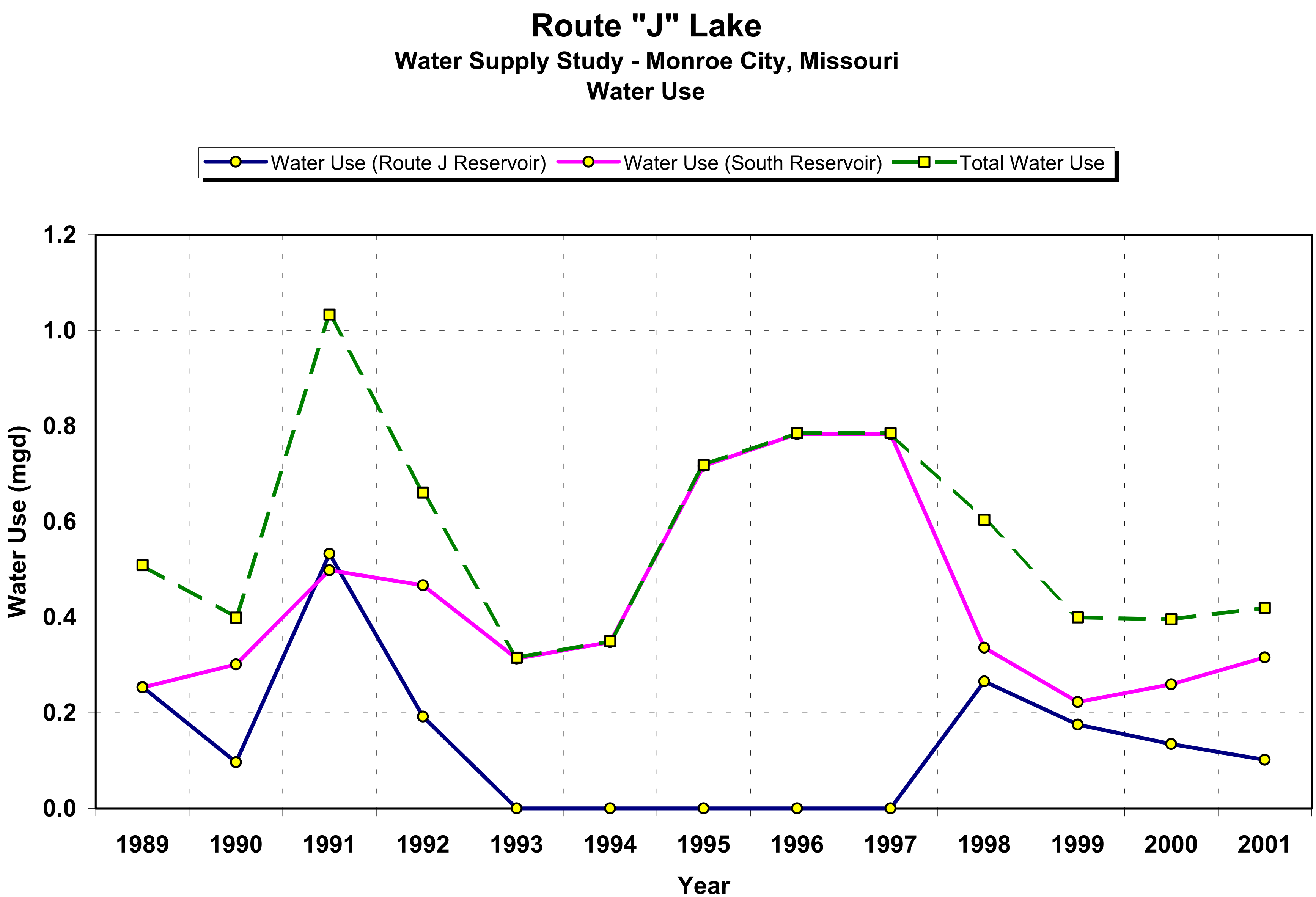

Route "J" Lake
Water Supply Study - Monroe City, Missouri
Water Use
Water Use (Route J Reservoir)
Water Use (South Reservoir)
Total Water Use
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Water Use (mgd)
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 34.2

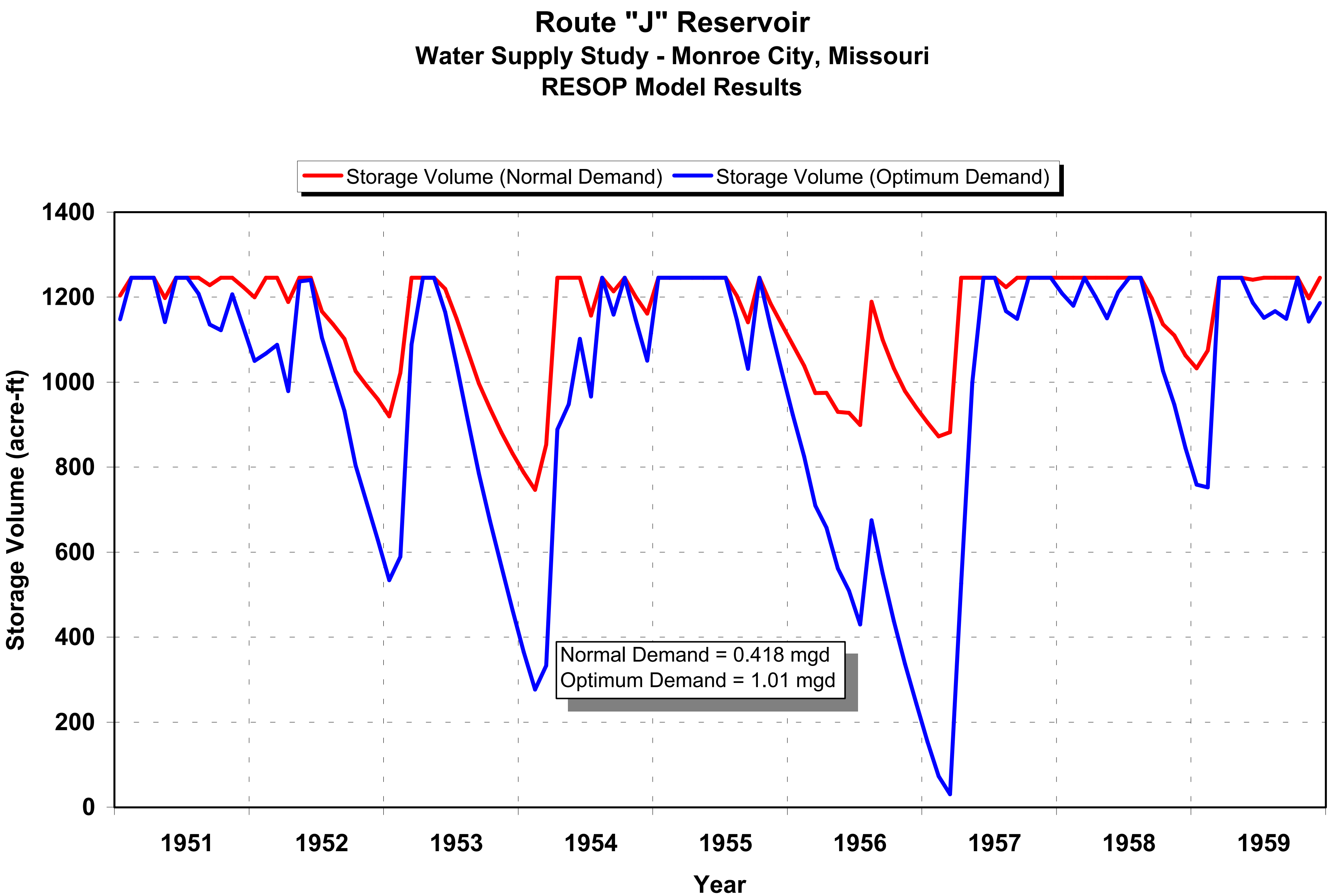

Route "J" Reservoir
Water Supply Study - Monroe City, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Storage Volume (acre-ft)
1400
1200
1000
800
600
400
200
0
Normal Demand = 0.418 mgd
Optimum Demand = 1.01 mgd
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 34.3

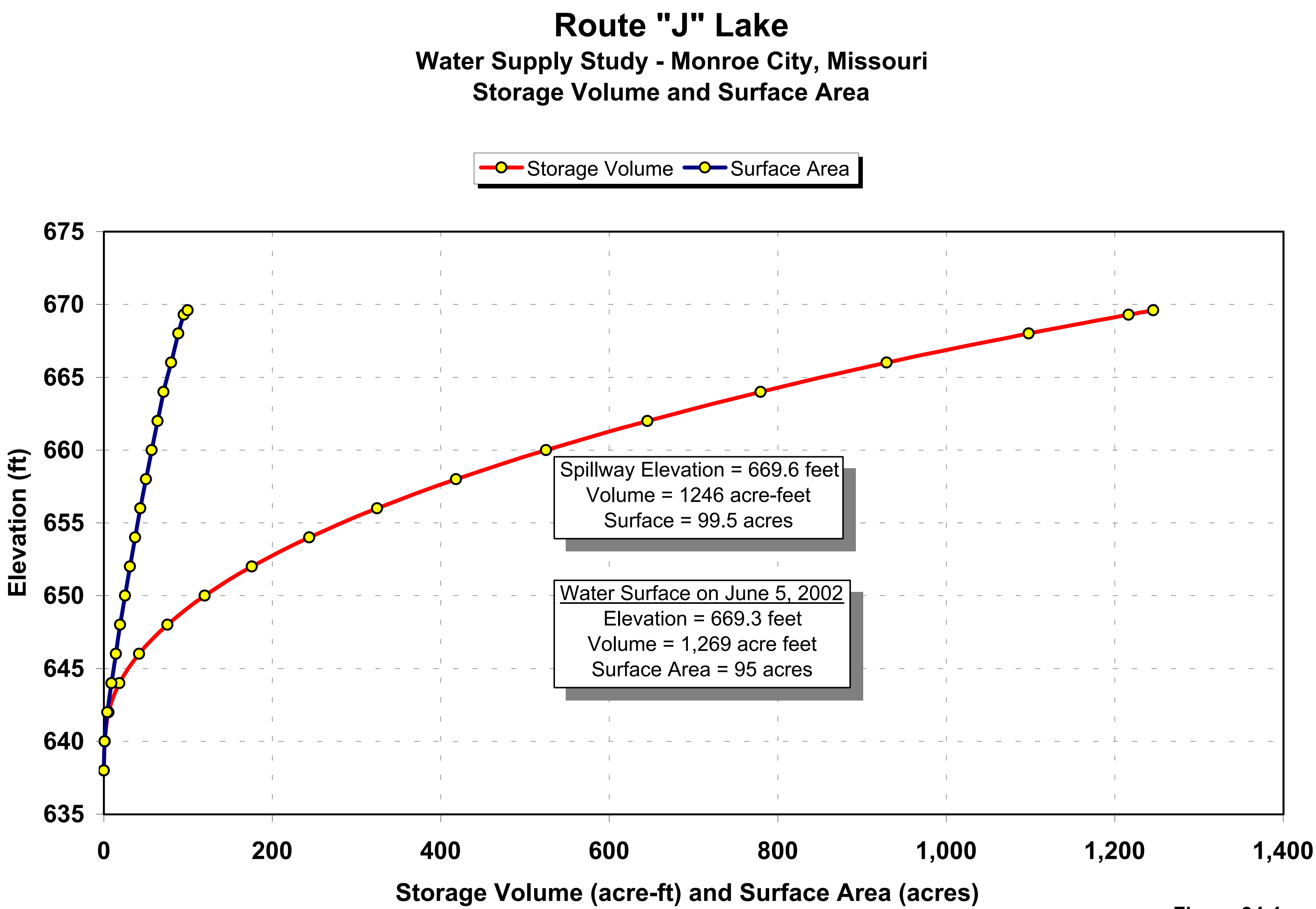

Route "J" Lake
Water Supply Study - Monroe City, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Spillway Elevation = 669.6 feet
Volume = 1246 acre-feet
Surface = 99.5 acres
Water Surface on June 5, 2002
Elevation = 669.3 feet
Volume = 1,269 acre feet
Surface Area = 95 acres
Elevation (ft)
675
670
665
660
655
650
645
640
635
0
200
400
600
800
1,000
1,200
1,400
Storage Volume (acre-ft) and Surface Area (acres)

Figure 34.4

Mozingo Creek Reservoir
Drought Assessment Analysis - Maryville, Missouri
Drought Assessment Analysis

I. Overview

Mozingo Creek Reservoir is located in Northwest Missouri, in Nodaway County, and owned by the City of Maryville. It is designed for flood control, recreation and municipal water supply. The lake was planned and constructed as a watershed lake through the United States Department of Agriculture's Natural Resource Conservation Service (NRCS) small watershed program (PL-566) in cooperation with the City of Maryville. Maryville began using water from Mozingo Creek Lake in 1999. The lake is located about 3 miles east of Maryville. Prior to construction of this lake, water was taken from the 102 River. The Mozingo Creek Reservoir serves a population of approximately 9,872 with an estimated water demand of 1.33 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources). Maryville sells finished water to Nodaway Public Water Supply District #1. In 2001 Maryville reported water use of 1.92 million gallons per day. The trend of water use has been increasing about 2.3 percent per year for the period 1987 through 2004.

The City of Maryville draws water directly from the reservoir to the treatment facility, and the reservoir, itself, can be supplemented with water from 102 River. Figure 35.2 illustrates historical water demand by Maryville.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

II. Drought Assessment Summary

The Mozingo Creek Reservoir is capable of meeting Maryville's demand for water during times of extended drought. The 2001 demand on the reservoir was approximately 1.92 million gallons per day (figure 35.2), and when this demand volume is applied to the reservoir during the drought of record, which was in the 1950's, the reservoir would have 12,000 acre-feet of water remaining. The estimated optimum yield from Mozingo Creek Reservoir is 2.9 million gallons per day. By utilizing the recreation storage the lake would supply 4.0 million gallons per day. The previous water supply system on the 102 River has remained in place and can supplement the water supply from Mozingo Creek Reservoir if needed. Figure 35.3 illustrates these results.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

Mozingo Creek Lake was planned, designed and constructed in cooperation between the city of Maryville and NRCS. A bathymetric map of the lake area is maintained by NRCS.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Mozingo Creek Reservoir conducted by the NRCS. Surface area of the lake and associated storage volume capacities are illustrated in figure 35.4.

Storage allocation:
Sediment………………………………………………………………….= 2410 acre-feet
Recreation………………………………………………………………... = 5285 acre-feet
Water Supply…………………………………………………………….. = 9,825 acre-feet

Mozingo Creek Reservoir Physical Data

Mozingo Creek Lake			
Elevation (feet)	Area (acres)	Volume (acre-ft)	
1010	0	0	
1020	70	350	
1030	150	1,250	
1040	320	3,325	
1045	180	5,500	
1050	640	8,300	
1055	840	12,000	
1060	960	16,500	
1065	1,240	22,000	
1070	1,360	28,500	
1075	1,640	36,000	

Principal spillway elevation = 1060.5 feet.
Emergency spillway elevation = 1067.3 feet.

[LIMITS]

Maximum pool storage……………………………………………………17,520 acre-feet
Minimum pool storage……………………………………………………2,410 acre-feet
Drainage basin size……………………………………………………..20.92 square miles

Initial storage was equated to the reservoir at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Mozingo Creek Reservoir is estimated to be 1.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Rainfall data was obtained from the Maryville rain gauge for the period 1951 through 1959.

Average precipitation in Maryville was 35.0 inches between 1950 and 2000. Precipitation values for the drought of record were obtained from Maryville, Missouri reporting station (2 miles northeast of Maryville). The most severe drought occurred between 1953 and 1957 with annual precipitation values of 22.41 inches, 38.36 inches, 29.78 inches, 23.22 inches, and 32.32 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the White Cloud Creek gauge (a tributary of the 102 River), located near Maryville. The drainage area monitored by this stream gauge covers approximately 6.00 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Maryville, individual storm events were considered. Antecedent rainfall was determined for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Mozingo Creek Reservoir due to evaporation. This data was supplemented and compared with evaporation data from the station at Spickard, Missouri. An adjustment factor of 0.76 was applied to adjust from pan to lake evaporation.

[DEMAND]

Water demand for Maryville was obtained from records maintained by the Missouri Department of Resources (Major Water Users database). The 2001 demand for water was 1.92 million gallons per day, which is used for this analysis. The rate of increase for demand has been 2.3 percent per year between 1987 through 2004.

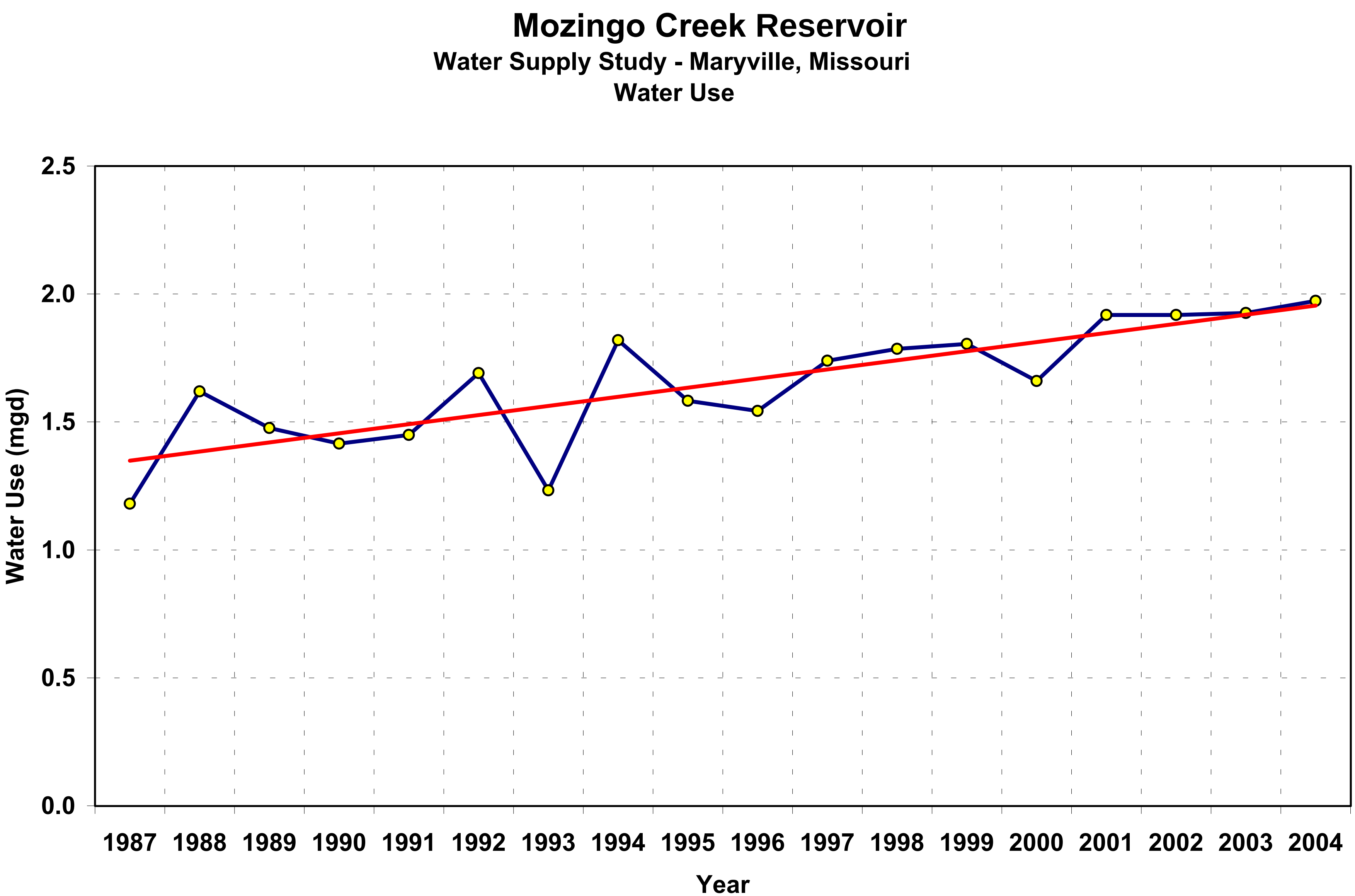

Mozingo Creek Reservoir
Water Supply Study - Maryville, Missouri
Water Use
Water Use (mgd)
0.0
0.5
1.0
1.5
2.0
2.5
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Year

Figure 35.2

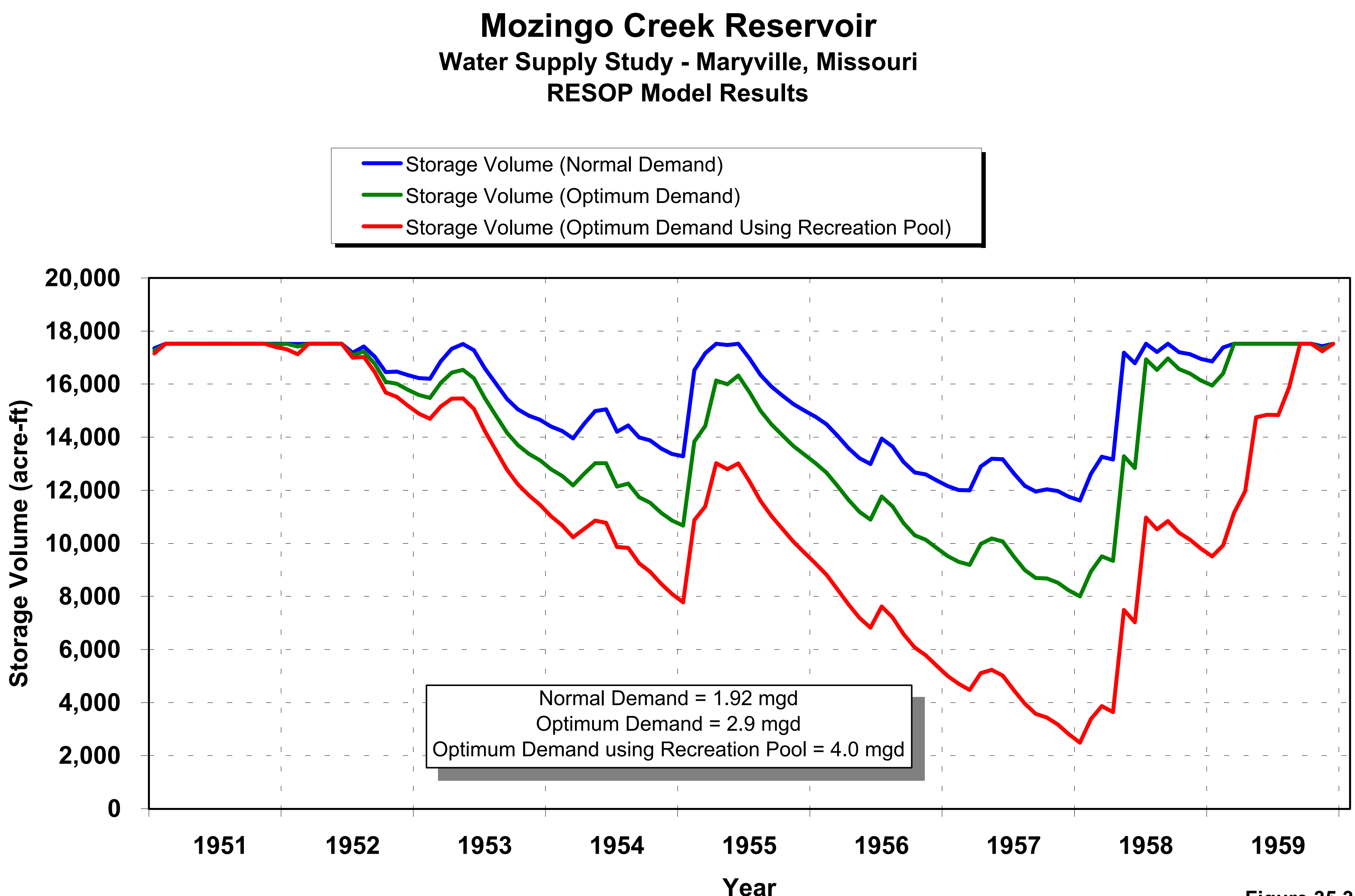

Mozingo Creek Reservoir
Water Supply Study - Maryville, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Storage Volume (Optimum Demand Using Recreation Pool)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Storage Volume (acre-ft)
Normal Demand = 1.92 mgd
Optimum Demand = 2.9 mgd
Optimum Demand using Recreation Pool = 4.0 mgd
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 35.3

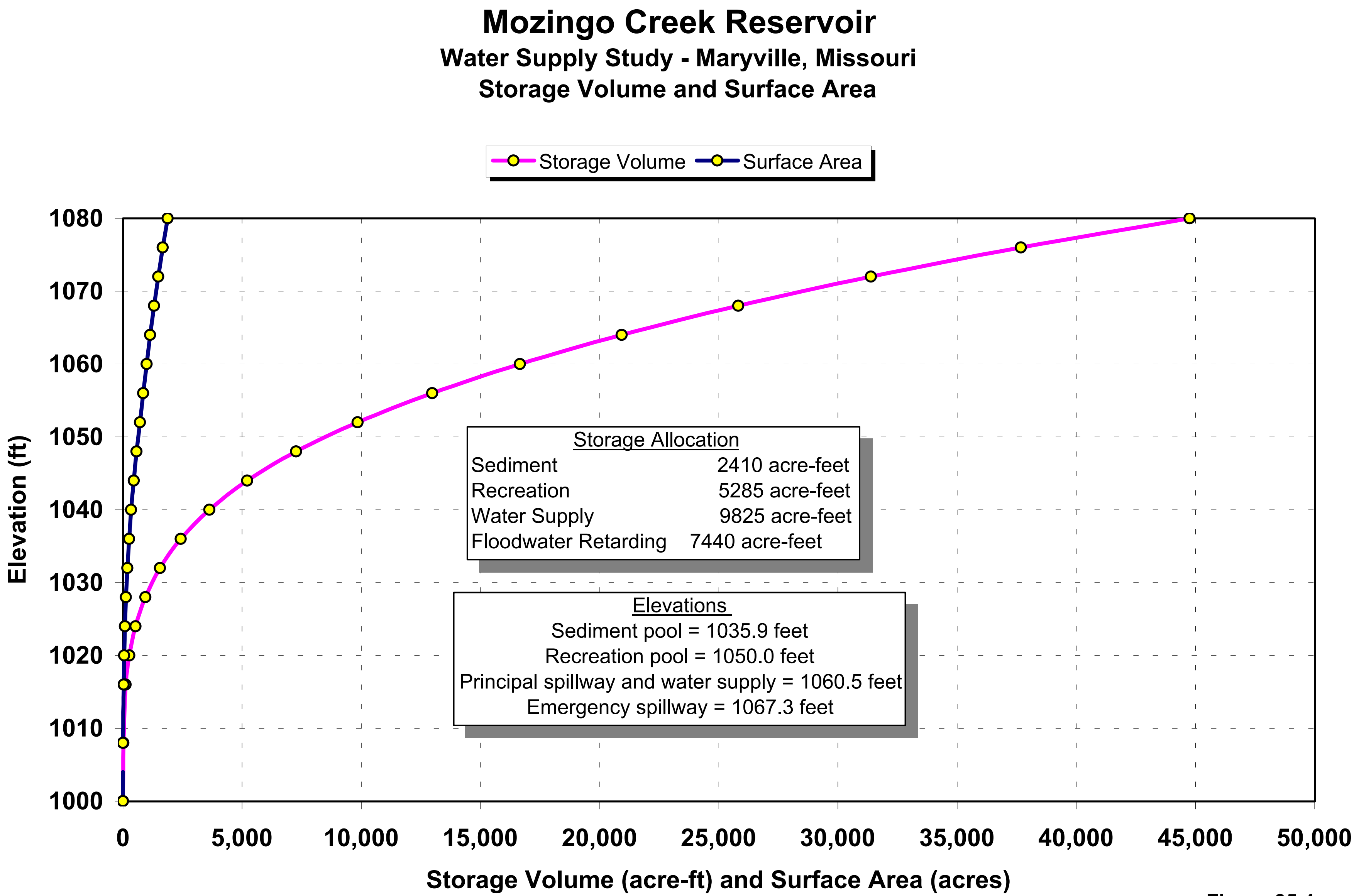

Mozingo Creek Reservoir
Water Supply Study - Maryville, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Elevation (ft)
1080
1070
1060
1050
1040
1030
1020
1010
1000
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
Storage Volume (acre-ft) and Surface Area (acres)
Storage Allocation
Sediment 2410 acre-feet
Recreation 5285 acre-feet
Water Supply 9825 acre-feet
Floodwater Retarding 7440 acre-feet
Elevations
Sediment pool = 1035.9 feet
Recreation pool = 1050.0 feet
Principal spillway and water supply = 1060.5 feet
Emergency spillway = 1067.3 feet

Figure 35.4

Rock House Lake
Water Supply Study – Ridgeway, Missouri
Drought Assessment Analysis

I. Overview

Rock House Lake (figure 36.1) is located in northeastern Harrison County, Missouri, four miles east of the City of Ridgeway. Rock House Reservoir is the primary source of water for the City of Ridgeway. The Rock House Reservoir serves a population of approximately 530 with 229 connections. The Rock House Reservoir serves a population of approximately 530 with an estimated water demand of 0.03 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

Ridgeway is now obtaining their water supply from Harrison County rural water supply district Number 3. In the past, Ridgeway's water supply came from Rock House Lake. Water was pumped from Rock House Lake to a storage lake located one mile west of the city of Ridgeway, in sections 32, Mission Township. Water was than pumped to the treatment plant for treatment. The storage lake's drainage area is small and contributed very little to Ridgeway's water needs. Rock House Lake was built as one of the Natural Resource Conservation Service's (NRCS) Panther Creek PL-566 watershed project lakes. Plans are being made to connect the city of Ridgeway to Harrison County rural water supply district Number 3.

Historical demand on the reservoir in 1999 was reported to be 38,000 gallons per day, which is the demand value used in this model. Figure 36.2 illustrates historical water demand on the Rock House Reservoir.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Rock House Reservoir. The model assumes that 'Normal' demand for Ridgeway is 38,000 gallons per day and that 'Optimum' yield from the lake is 246,000 gallons per day. Figure 36.3 illustrates these relationships.

II. Drought Assessment Summary

The Rock House Reservoir is capable of supplying Ridgeway's demand for water during times of drought. The 2004 demand on the reservoir was approximately 38,000 gallons per day, and when this demand value is applied to the reservoir during the drought of record in the 1950's, water volume in the reservoir would be reduced from 461 acre-feet to 280 acre-feet. The estimated Optimum yield from Rock House Reservoir is 246,000 gallons per day. This optimum yield estimate includes the lake volume allocated to sediment accumulation.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Rock House Reservoir conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on May 28, 2003. Surface area of the lake and associated storage volume capacities are illustrated in figure 36.4.

Rock House Lake Physical Data

Rock House Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	Additional notes
888	0.01	0.01	
890	0.6	0.7	
892	2.1	2.9	
894	9.8	14.2	
896	20.6	43.3	
898	28.3	93	
900	38.0	159	
902	43.3	240	
904	51.6	334	
906	58.2	443	
906.3	60.8	461	Spillway and Lake conditions on May 28, 2003

[LIMITS]
Maximum storage ....4.61 acre-feet
Minimum storage ....50 acre-feet
Drainage basin size .... 8.94 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959

[SEEPAGE]

Seepage from Rock House Lake is approximately 1.5 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Precipitation values for the drought of record were obtained from the Bethany, Missouri rain gauge.

Average precipitation in Bethany was 37.24 inches between 1970 and 2000. Precipitation values for the drought of record were obtained from Bethany, Missouri (approximately 8-miles south of Ridgeway). The most severe drought occurred between 1953 and 1957 with annual precipitation values in Bethany of 24.09 inches, 32.05 inches, 27.00 inches, 24.31 inches, and 32.27 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the East Fork Big Creek stream gauge, located at Bethany, Missouri. The drainage area monitored by this stream gauge covers approximately 95 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Ridgeway, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Rock House Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

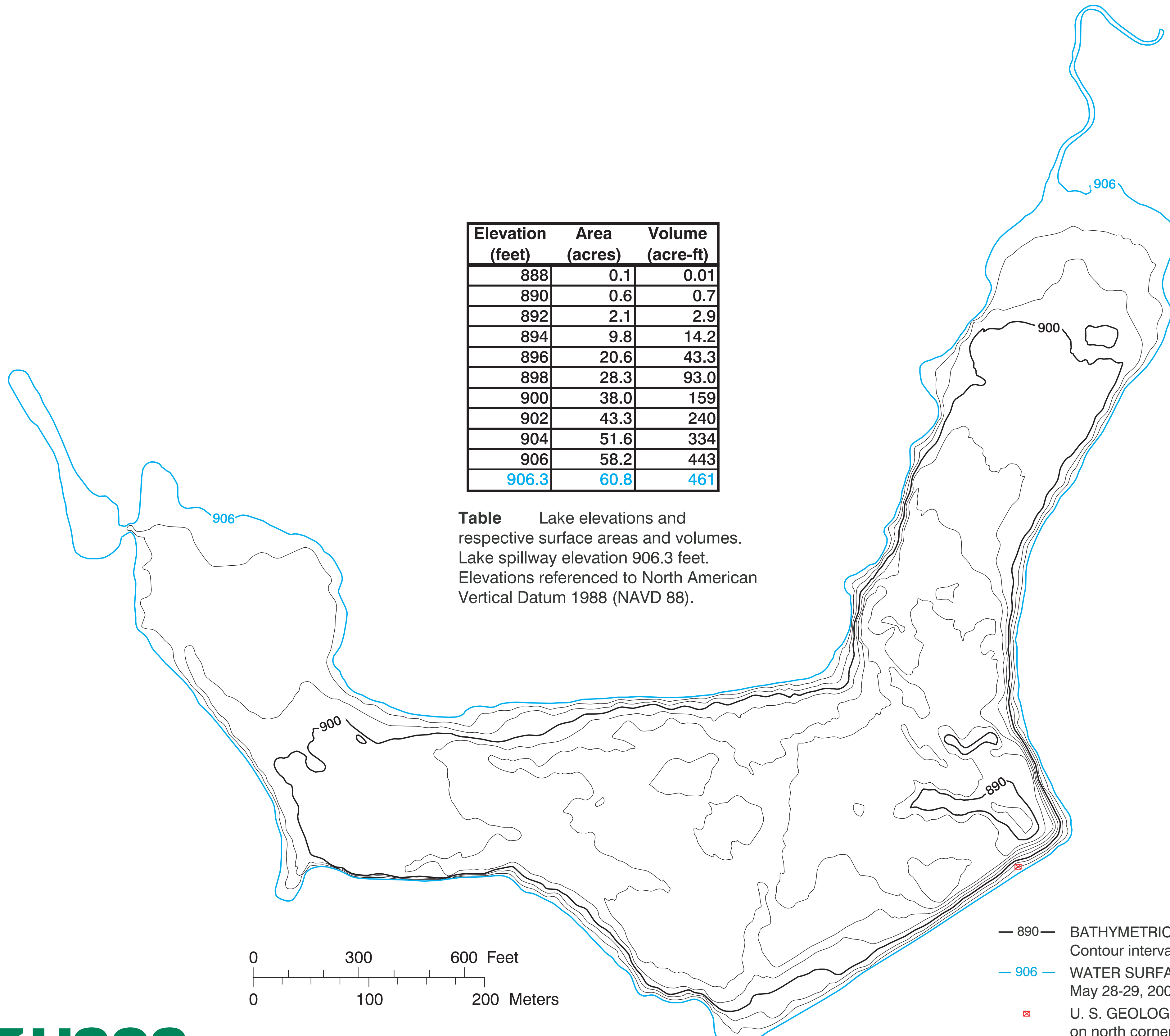
The value for this report was 38,000 gallons per day. Figure 36.2 illustrates the historical usage.

City records reported to "Missouri Department of Natural Resources" major water users database determined water demand. Ridgeway reported using 13,991,000 gallons of water in 1999 for an average 38,000 gallons of water per day.

ROCK HOUSE LAKE

Elevation (feet)	Area (acres)	Volume (acre-ft)
888	0.1	0.01
890	0.6	0.7
892	2.1	2.9
894	9.8	14.2
896	20.6	43.3
898	28.3	93.0
900	38.0	159
902	43.3	240
904	51.6	334
906	58.2	443
906.3	60.8	461

Table Lake elevations and respective surface areas and volumes. Lake spillway elevation 906.3 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).



EXPLANATION

— 890 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet.

— 906 — WATER SURFACE—Shows approximate elevation of water surface, May 28-29, 2003 (table 22) actual elevation 906.3.

⊠ U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on north corner of concrete drop-box spillway. Elevation 910.3 feet.

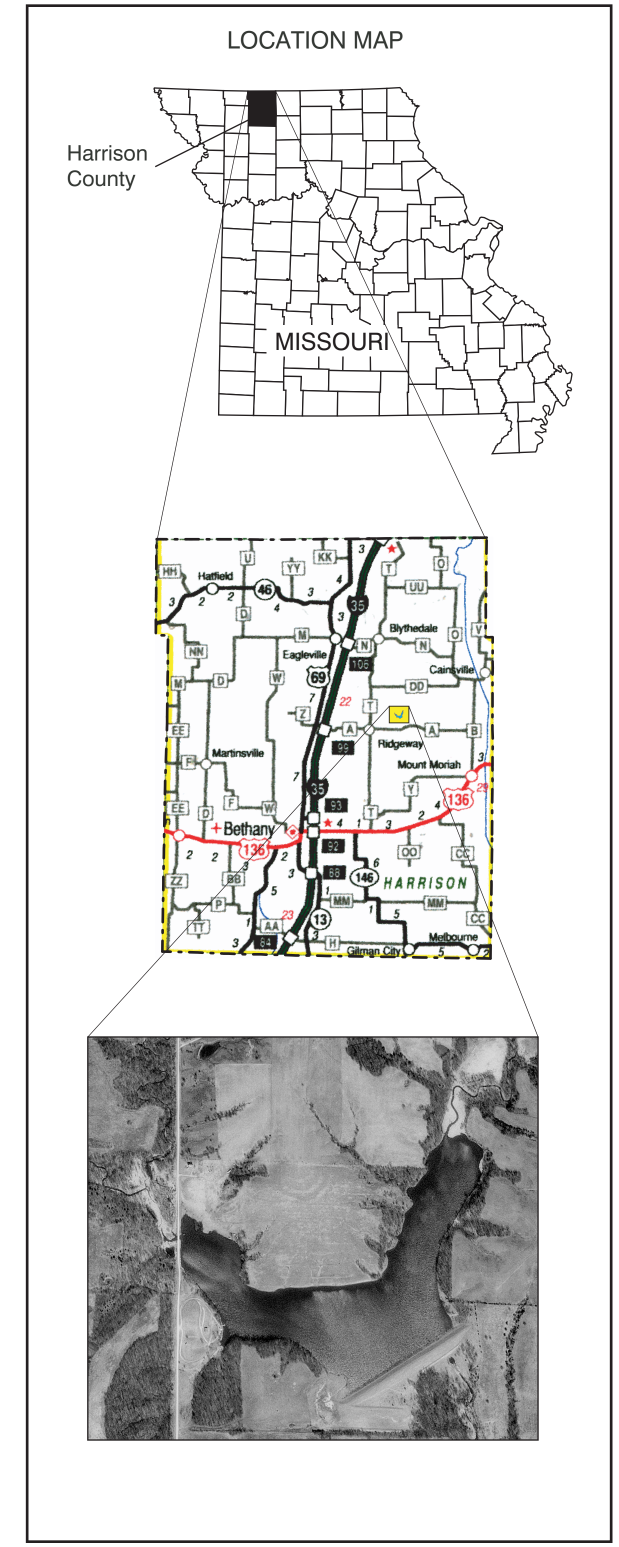


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Figure 36.1

Bathymetric map and area/volume table for Rock House Lake near Ridgeway, Missouri.

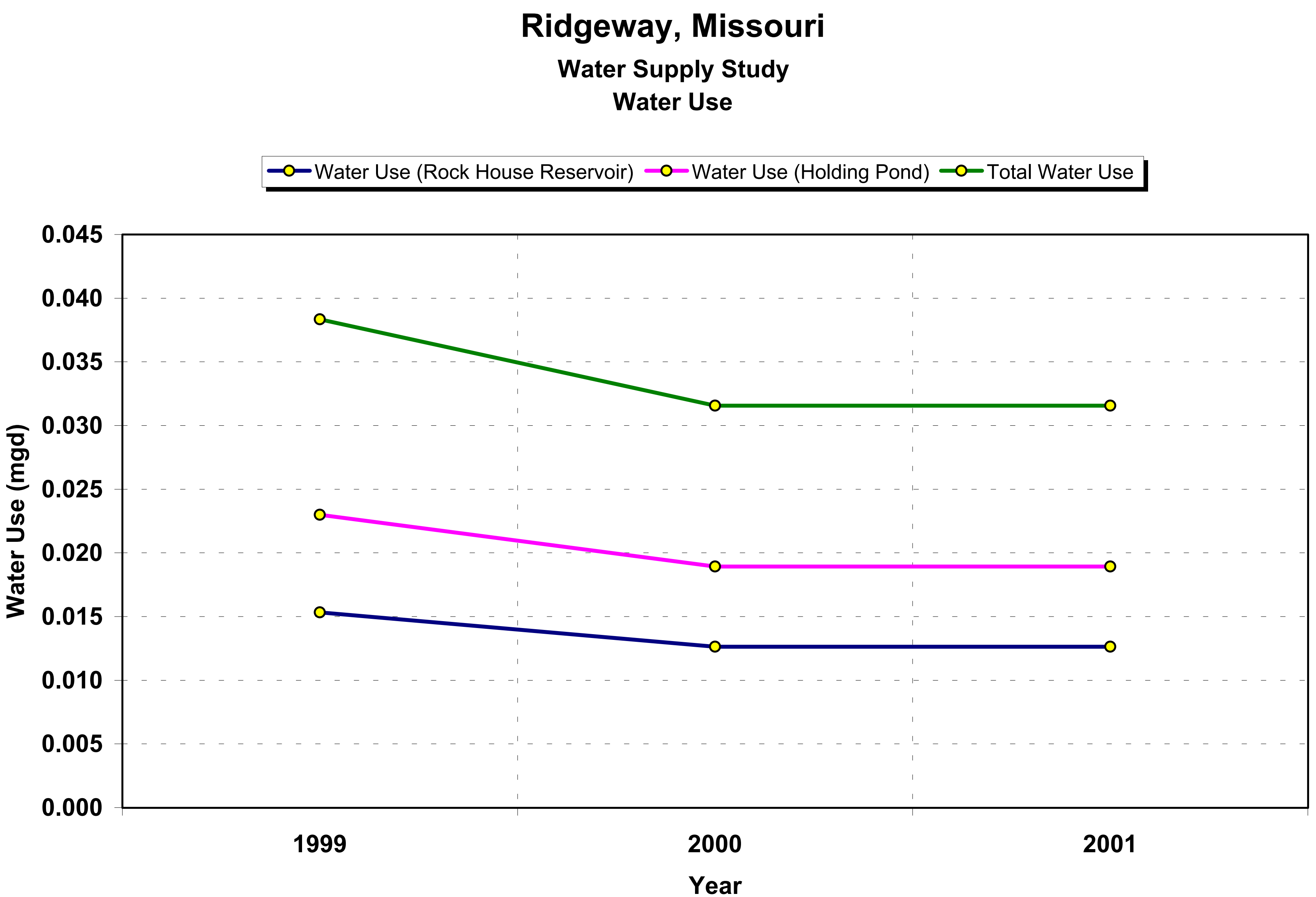

Ridgeway, Missouri
Water Supply Study
Water Use
Water Use (Rock House Reservoir)
Water Use (Holding Pond)
Total Water Use
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Water Use (mgd)
1999
2000
2001
Year

Figure 36.2

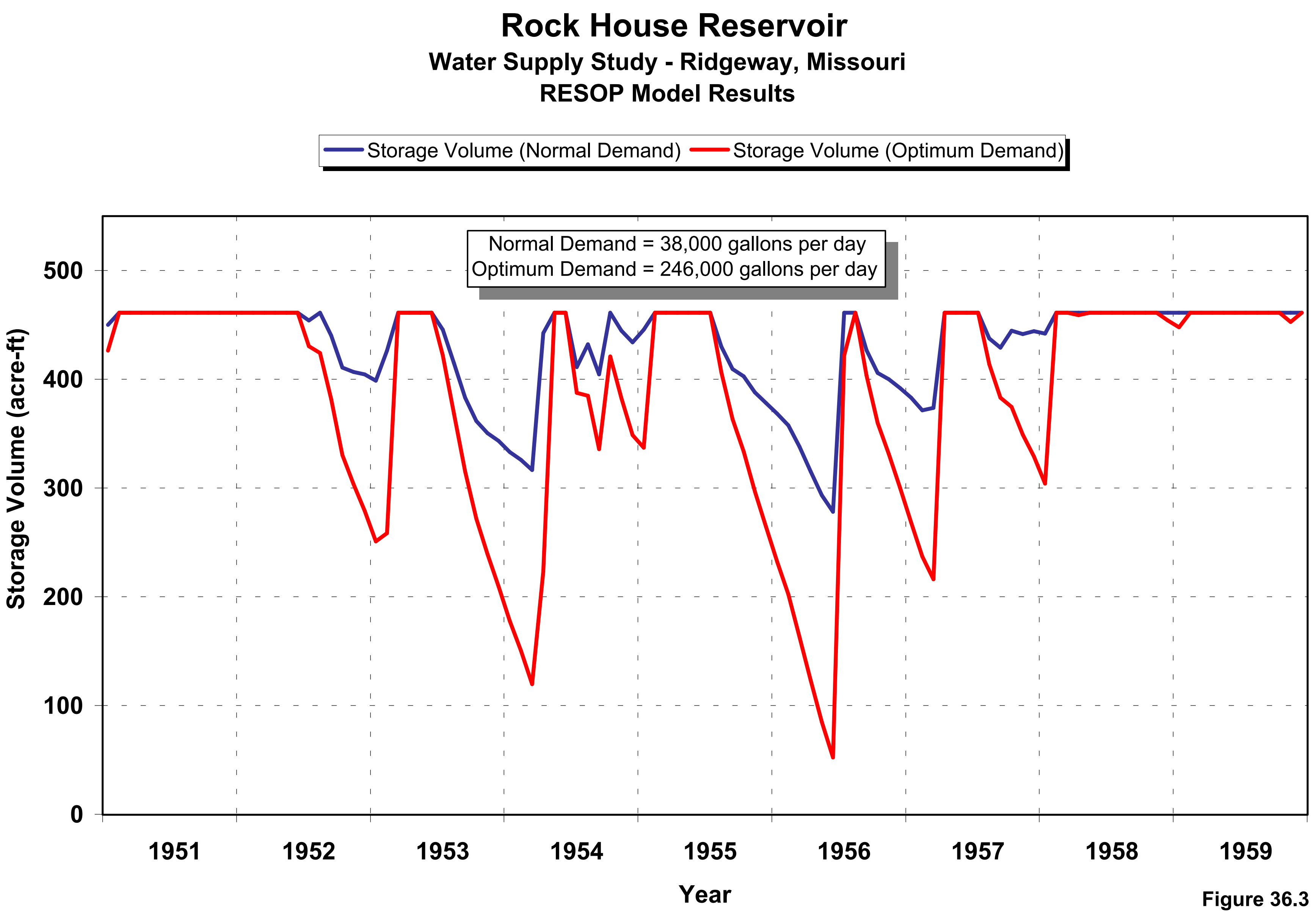

Rock House Reservoir
Water Supply Study - Ridgeway, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 38,000 gallons per day
Optimum Demand = 246,000 gallons per day
Storage Volume (acre-ft)
0
100
200
300
400
500
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 36.3

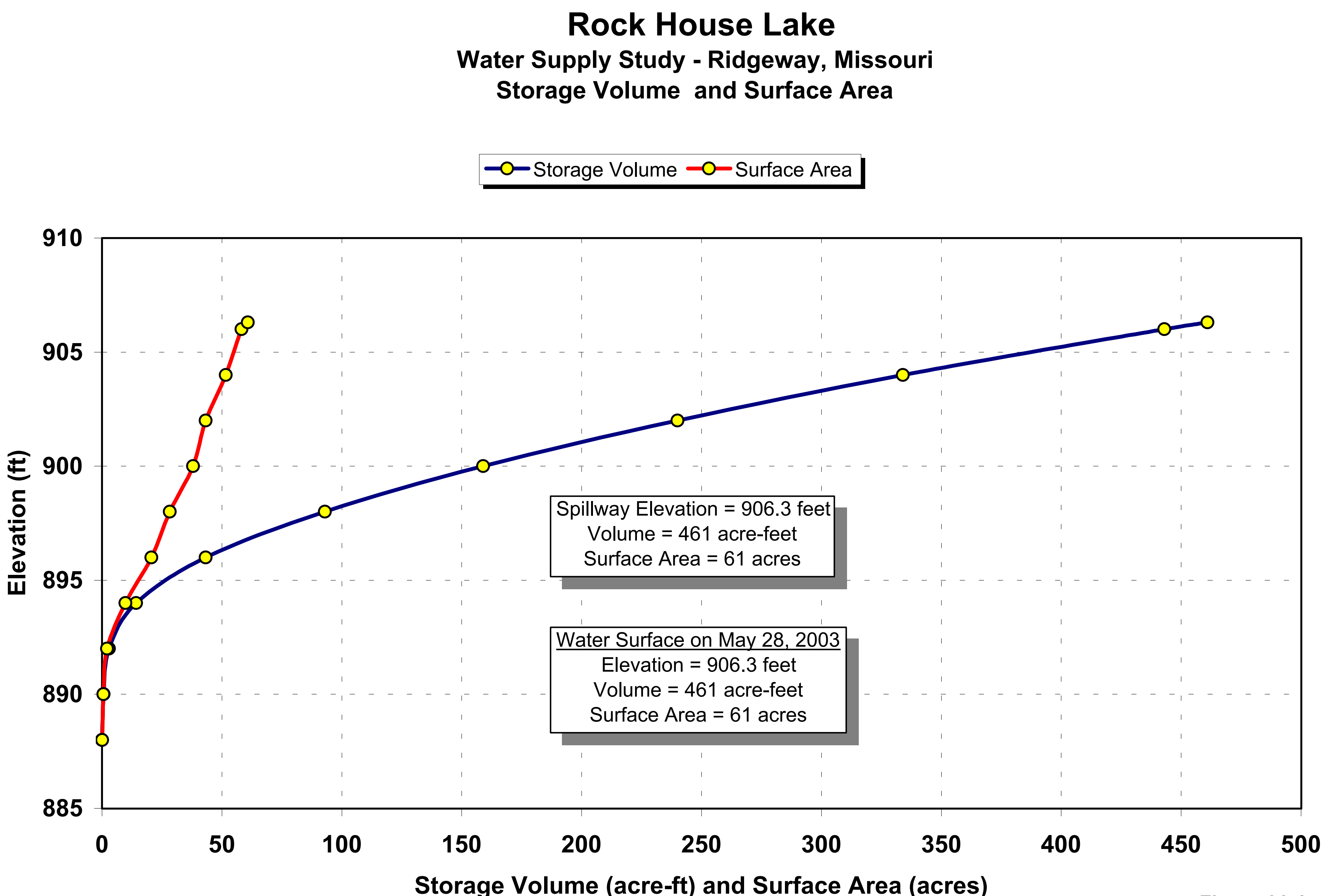

Rock House Lake
Water Supply Study - Ridgeway, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
910
905
900
895
890
885
Elevation (ft)
0
50
100
150
200
250
300
350
400
450
500
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 906.3 feet
Volume = 461 acre-feet
Surface Area = 61 acres
Water Surface on May 28, 2003
Elevation = 906.3 feet
Volume = 461 acre-feet
Surface Area = 61 acres

Figure 36.4

Spring Fork Lake
Water Supply Analysis – Sedalia, Missouri
Drought Assessment Analysis

I. Overview

Sedalia is located in Pettis County Missouri, in West Central Missouri. Spring Fork Lake is approximately 5 miles south of Sedalia on Spring Fork Creek (figure 37.1). The City of Sedalia also sells finished water to Pettis-Johnson-Saline PWSD # 1. The Sedalia water supply system serves a population of approximately 20,339 with an estimated water demand of 3.20 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

Sedalia gets their water from two sources, Spring Fork Reservoir and nine wells. In year 2001, Sedalia used a total of 990,657,900 gallons of water, 64 percent came from Spring Fork Lake and the rest from nine wells. In 2001 the City of Sedalia withdrew an average of 1.735 million gallons per day from Spring Fork Reservoir and 0.979 million gallons per day from the nine wells. Figure 37.2 illustrates historical water use from Spring Fork Reservoir and the nine wells. Water use trend has increased 4.7 percent per year between 1998 and 2004. The 2001 demand from the reservoir was used to analyze Spring Fork Reservoir. This analysis is to study lake and surface water supplies. Contribution from the wells was not considered part of the reservoir analysis.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

One scenario was modeled for Spring Fork Creek Reservoir. Although nine groundwater wells are available to supplement this water supply, the contribution of these wells to available supplies was not considered within the context of this model. The model assumes that 'Normal' demand for Sedalia is 1.735 million gallons per day and that 'Optimum' yield from the lake is 1.059 million gallons per day. Figure 37.3 illustrates these relationships.

II. Drought Assessment Summary

The Spring Fork Reservoir is not able to supply all of Sedalia's needs. Contribution from the wells is required. The 2001 demand on the reservoir was approximately 1.735 million gallons per day. When this demand value is applied to the reservoir during the drought of record in the 1950's, water deficits would have occurred in October 1953 through December 1954 and again October 1956 through March 1957. The estimated optimum demand from Spring Fork Reservoir is 1.059 million gallons per day (figure 37.3).

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Spring Fork Reservoir conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on April 17, 2002. Surface area of the lake and associated storage volume capacities are illustrated in figure 37.4.

Spring Fork Reservoir Physical Data

Spring Fork Reservoir			
Elevation (feet)	Area (acres)	Storage (acre-feet)	Additional notes
870	0.73	0.554	
872	5.09	5.72	
874	13.04	23.50	
876	22.05	57.51	
878	32.46	111.79	
880	43.07	186.96	
882	53.29	283.20	
884	65.92	401.93	
886	80.43	548.43	
888	97.18	725.32	
890	112.43	934.35	
891.6	122.74	1,122.21	Lake conditions on April 17, 2002
892	126.95	1,171.26	
892.6	131.24	1,249.74	Spillway

[LIMITS]

Maximum storage……………………………………………………….1249 acre-feet
Minimum storage…………………………………………………………...60 acre-feet
Drainage basin size………………………………………………..10.98 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Spring Fork Reservoir is estimated to be approximately 2.25 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Rainfall data came from the Sedalia, Missouri rain gauge for the period 1951 through 1959.

Average precipitation in Sedalia for the period 1950 through 2000 was 40.5 inches. The most severe drought occurred between 1953 and 1957 with annual precipitation values in Sedalia of 22.17 inches, 34.94 inches, 35.12 inches, 22.14 inches, and 39.87 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Lamine River Gauge, located downstream of Spring Fork Lake. The drainage area monitored by this stream gauge covers approximately 598 square miles.

Flat Creek gauge is located upstream of the Lamine River gauge, but only has records for the 1960's. Results of these gauges were compared for 1960's. The Flat creek gauge had 8 percent more runoff, on an annual basis, than the Lamine River gauge. Flat creek drainage has more cropland and the soils have higher clay content than Spring Fork Creek. As a result the Lamine River gauge records were a better fit for Spring Fork Lake drainage area runoff.

When this regional runoff value is inconsistent with precipitation values recorded for Sedalia, individual storm events were considered. Antecedent moisture was estimated for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information)

[EVAP.]

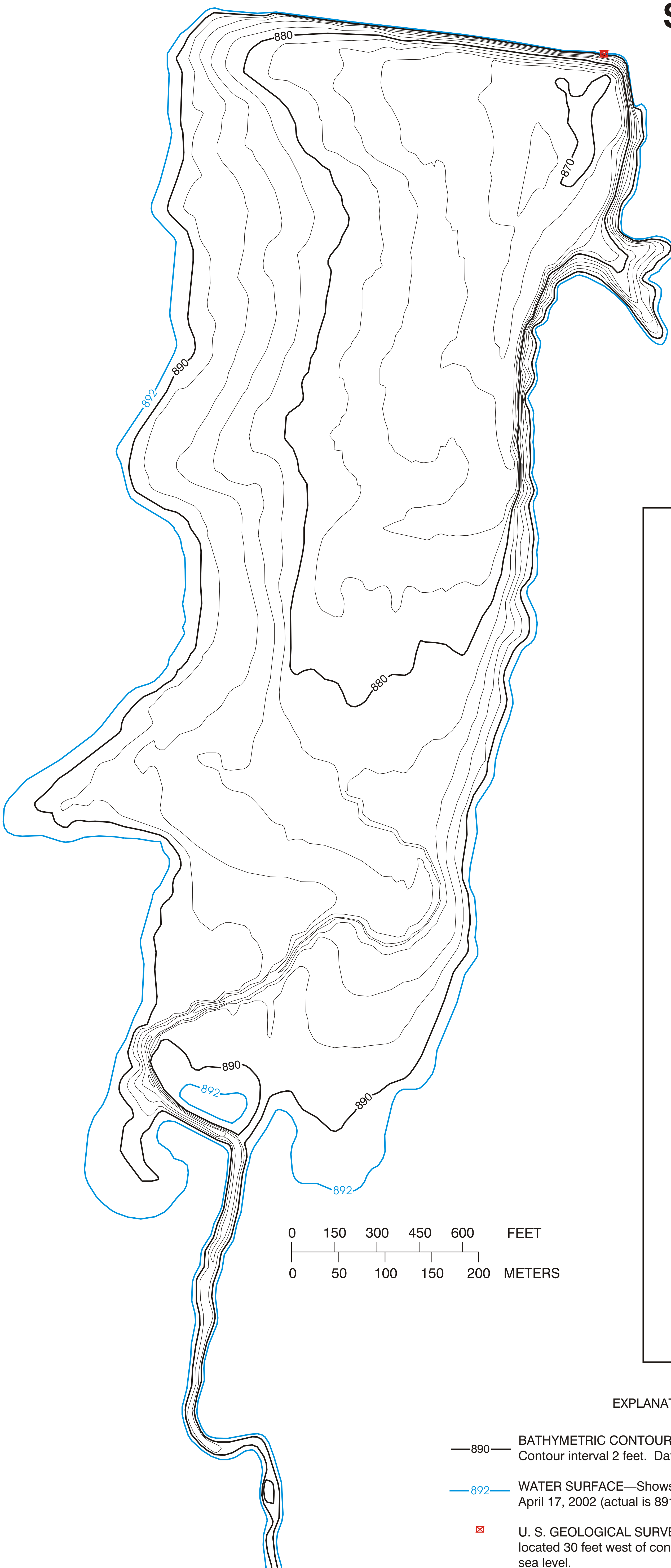
Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Spring Fork Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

Normal demand from Spring Fork Reservoir for 2001 is 1.735 million gallons per day, and was used for this analysis.

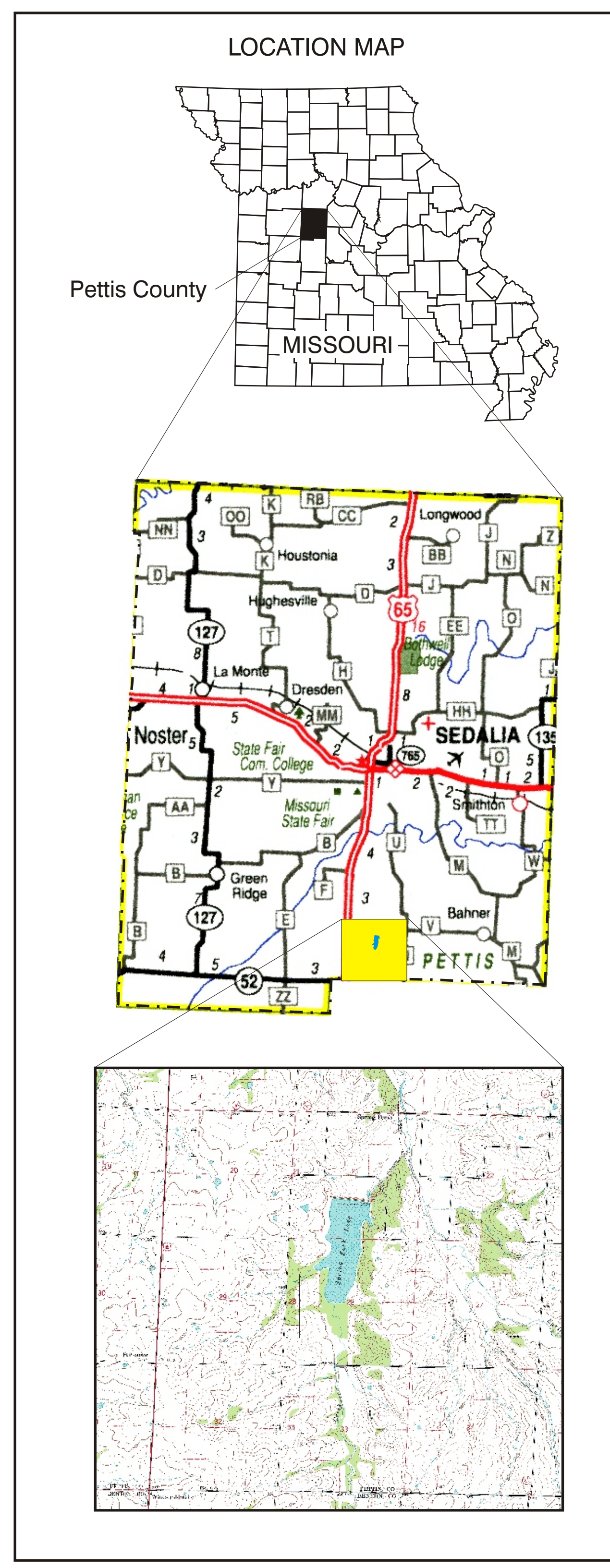
City records reported to Missouri Department of Natural Resources 'Major water users data base' were used to determined demand (figure 37.2). In 2001 Sedalia used a total of 990,657,900 gallons of water. Of this 633,275,000 gallons came from Spring Fork Reservoir and the rest came from their 9 wells.

SPRINGFORK LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
870.0	0.7	0.5
872.0	5.1	5.7
874.0	13.0	23.5
876.0	22.0	57.5
878.0	32.5	111.8
880.0	43.1	187.0
882.0	53.3	283.2
884.0	65.9	401.9
886.0	80.4	548.4
888.0	97.2	725.3
890.0	112.4	934.3
891.6	122.7	1,122.2
892.0	126.9	1,172.3
892.6	131.2	1,249.7

Table Lake elevations and respective surface areas and volumes. Spillway elevation is 892.6 feet.



EXPLANATION

890 BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level

892 WATER SURFACE—Shows approximate elevation of water surface, April 17, 2002 (actual is 891.6 feet, table 15). Datum is sea level.

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled Square located 30 feet west of concrete spillway. Elevation 892.6 feet. Datum is sea level.

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Bathymetric map and area/volume table of Springfork Lake near Sedalia, Missouri.

Figure 37.1

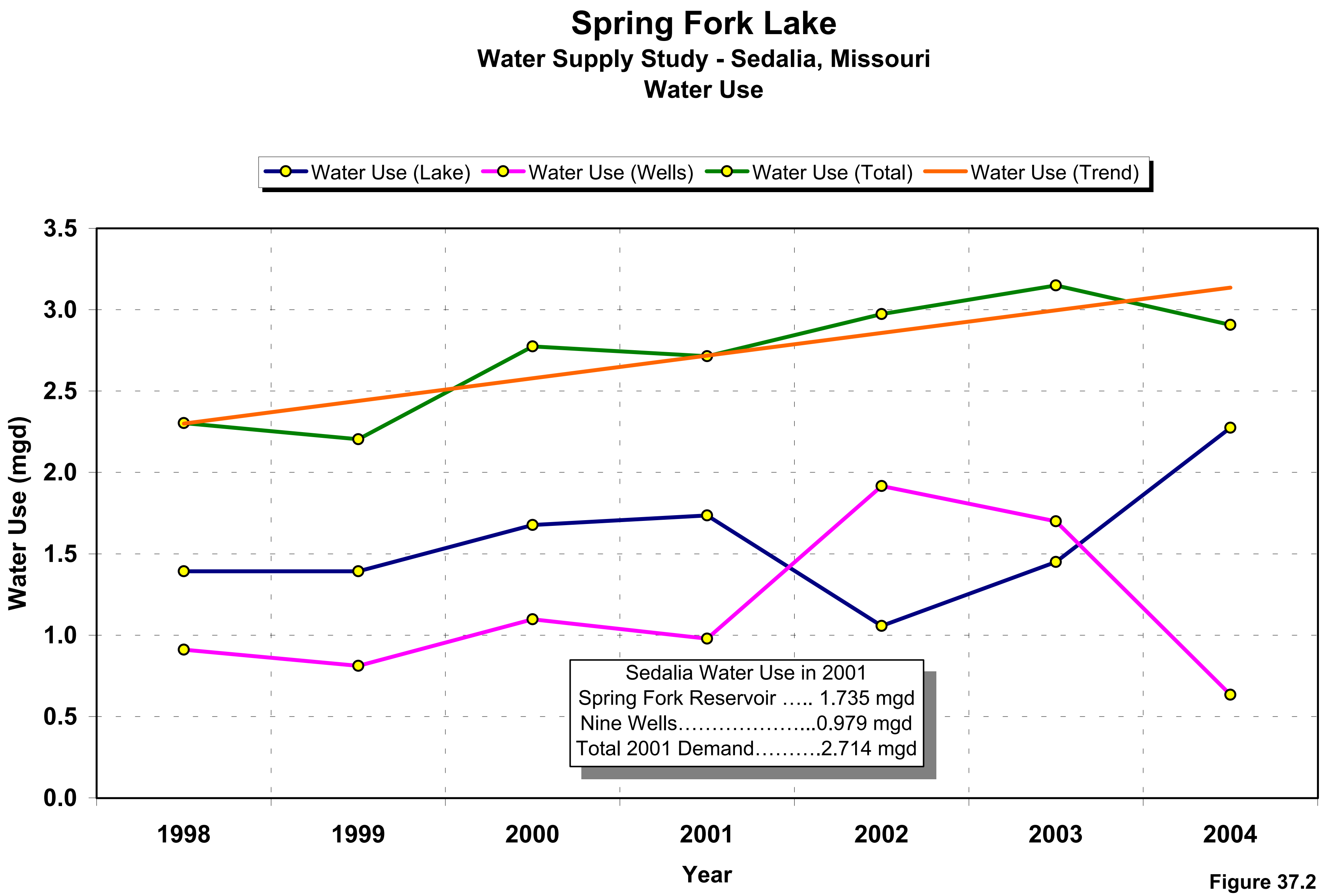

Spring Fork Lake
Water Supply Study - Sedalia, Missouri
Water Use
Water Use (Lake)
Water Use (Wells)
Water Use (Total)
Water Use (Trend)
Water Use (mgd)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1998
1999
2000
2001
2002
2003
2004
Year
Sedalia Water Use in 2001
Spring Fork Reservoir ….. 1.735 mgd
Nine Wells………………...0.979 mgd
Total 2001 Demand……….2.714 mgd

Figure 37.2

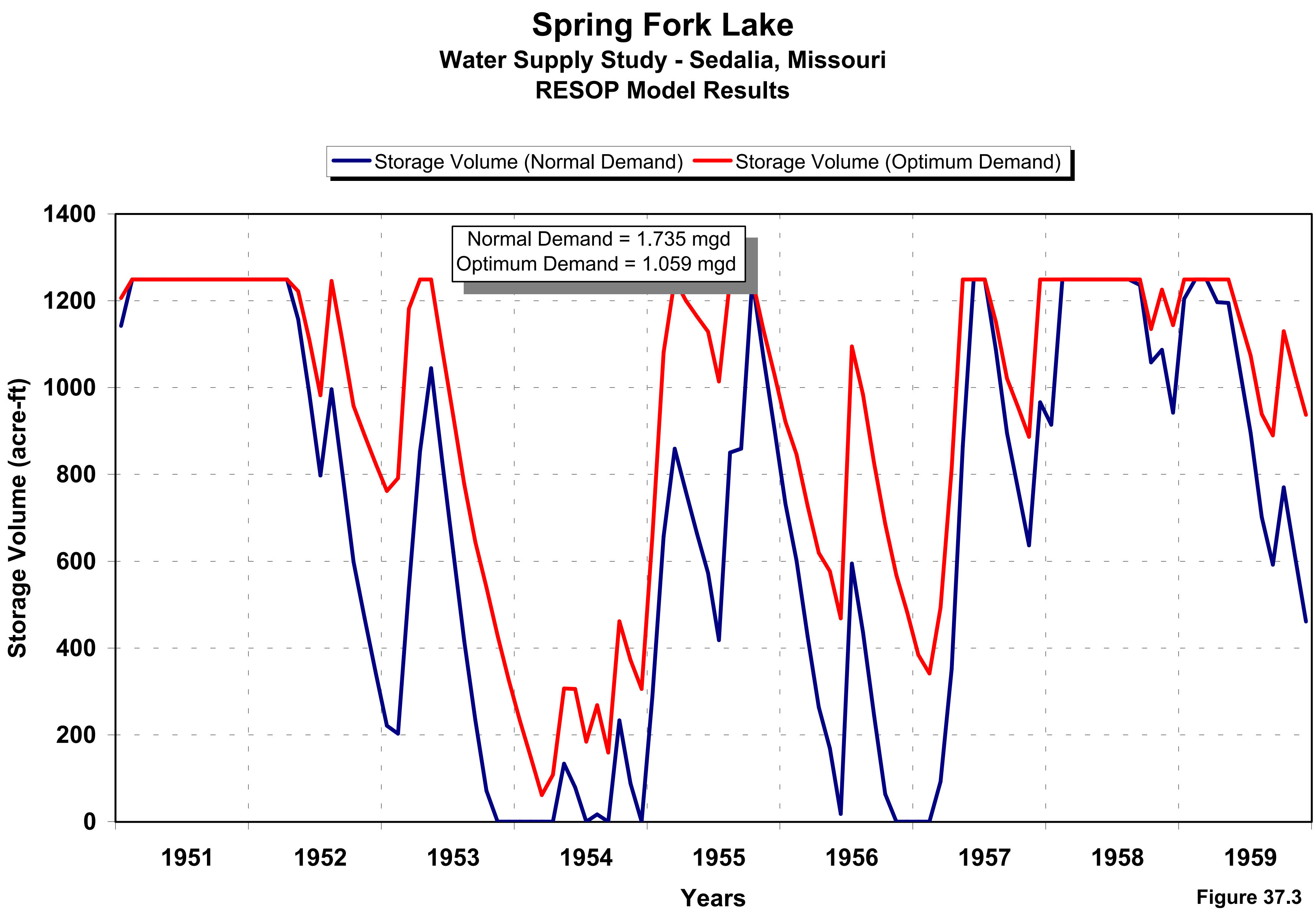

Spring Fork Lake
Water Supply Study - Sedalia, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 1.735 mgd
Optimum Demand = 1.059 mgd
Storage Volume (acre-ft)
1400
1200
1000
800
600
400
200
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 37.3

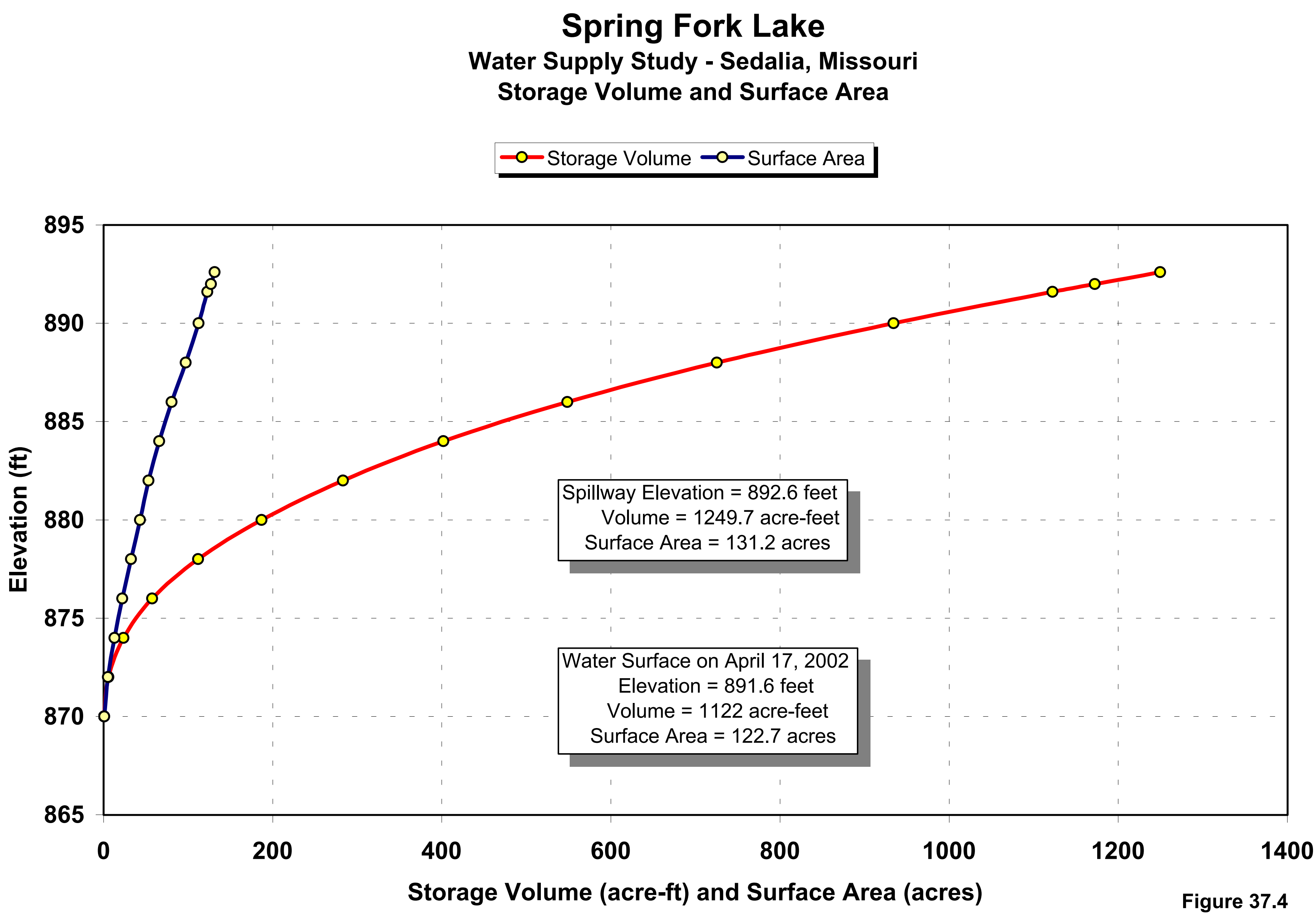

Spring Fork Lake
Water Supply Study - Sedalia, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
895
890
885
880
875
870
865
Elevation (ft)
0
200
400
600
800
1000
1200
1400
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 892.6 feet
Volume = 1249.7 acre-feet
Surface Area = 131.2 acres
Water Surface on April 17, 2002
Elevation = 891.6 feet
Volume = 1122 acre-feet
Surface Area = 122.7 acres

Figure 37.4

Shelbina Lake
Water Supply Analysis - Shelbina, Missouri
Drought Assessment Analysis

I. Overview

Shelbina is located in Shelby County, in northeast Missouri. Shelbina water supply comes from Shelbina Lake located about one mile north of the city (figure 38.1). The reservoir is maintained as near maximum capacity as is practical by diverting water into the lake from nearby Salt River. The Shelbina Reservoir serves a population of approximately 1,640 with an estimated water demand of 0.204 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

The Shelbina Reservoir has been supplemented with water diverted from the Salt River. Water is diverted from the Salt River with a pump rated at 600 gallons per minute. Year 2000 water use of 0.35 million gallons per day was used for this analysis. To meet the demand of 0.35 million gallons per day, water is pumped from the Salt River into the reservoir. It was assumed that irrigation water used to water the golf course would be replaced by pumping from the river and that the result of this would be no adverse effect. Historical water use from the Shelbina Reservoir is illustrated in figure 38.2.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program. Additional models were used to assess stream flow data for the Salt River, however, these models are not described here. The stream flow analysis procedure used for the Salt River is described in the Stream Analysis section of this report.

Three scenarios were analyzed for the Shelbina Reservoir system using the RESOP model:

1. The first scenario assesses the water budget for the reservoir with no additional sources of water (no pumping from the Salt River). An analysis of 'Normal' demand of 0.35 million gallons per day was applied to the reservoir during the drought of record to assess potential water deficits. A second analysis for 'Optimum' demand was performed to determine the optimum yield from the reservoir without additional water sources - this value represents the viable quantity of water available. Figure 38.3.a illustrates the relationship between these two analyses. When actual demand is applied to this scenario the reservoir's volume of water is entirely depleted and would not be capable of supplying water to meet demand. The optimum yield of 0.27 million gallons per day would not empty the reservoir but would draw down the water level to the point that the water would not be useable.

2. The second scenario analyzes 'Normal' demand and 'Optimum' demand for the Shelbina reservoir system when additional water is diverted to the reservoir from the Salt River (figure 38.3.b). Water from Salt River was diverted when the water level in the reservoir dropped to approximately 5 feet below the spillway elevation. Pumping was ceased when the reservoir was filled. A stream flow analysis was performed on the Salt River to determine the number of days per month stream flow would exceed 23 cubic feet per second to allow for in-stream flow needs and allow for pumping. Based on this analysis, it was estimated that water diverted from the Salt River to the reservoir would allow Shelbina to meet the demand of 0.35 million gallons per day. Optimum demand for this scenario would be 0.36 million gallons per day.

3. The third scenario analyzes ‘Normal’ demand and ‘Optimum’ demand for the Shelbina reservoir system when additional water is diverted to the reservoir from the Salt River (figure 38.3.c). Water from Salt River was diverted when the water level in the reservoir dropped to approximately 5 feet below the spillway elevation. Pumping was ceased when the reservoir was filled. A stream flow analysis was performed on the Salt River to determine the number of days per year that stream flow would exceed 2 cubic feet per second to allow for in-stream flow needs and allow for pumping. Seven-day duration ten-year frequency low flow discharge in Salt River was determined to be 2 cubic feet per second. Based on this analysis, it was estimated that water diverted from the Salt River to the reservoir would allow Shelbina to meet the demand of 0.35 million gallons per day. Optimum demand would be 0.49 million gallons per day.

II. Drought Assessment Summary

Data reported, by the city, to the Department of Natural Resources data base “Missouri major water users” for the period 1989 through 2001 shows the mean city water use of 0.35 million gallons per day. The demand of 0.35 million gallons per day can not be met by Shelbina’s Reservoir alone. This analysis shows the drought of record to be during the 1950’s. In order to assure a water supply during a drought period, such as the one in the 1950’s, it would be necessary to obtain supplemental water from another source. As a result the city diverts water from Salt River into Shelbina’s Reservoir. When the demand of 0.35 million gallons per day is applied to the reservoir, deficits would occur January through March 1954 and from October 1956 through April 1957. The estimated optimum yield from the Shelbina reservoir without supplementary supplies is 0.27 million gallons per day (figure 38.3.a).

The Shelbina reservoir can meet the demand of 0.35 million gallons per day with additional water diverted to the reservoir from the Salt River when stream flow exceeds 23 cubic feet per second in the river. Calculations and estimates are based on additional stream flow analysis models and a maximum pump rate of 600 gallons per minute. If water is diverted to the reservoir at the maximum pump rate (when stream flow allows) the optimum yield of the Shelbina reservoir is estimated to be 0.36 million gallons per day (figure 38.3.b).

The Shelbina reservoir is capable of meeting the demand of 0.35 million gallons per day with additional water diverted to the reservoir from the Salt River when stream flow exceeds the 7-day duration 10-year frequency low flow discharge of 2 cubic feet per second in the river. Calculations and estimates are based on additional stream flow analysis models and a maximum pump rate of 600 gallons per minute. If water is diverted to the reservoir at the maximum pump rate (when stream flow allows) the optimum yield of the Shelbina reservoir is estimated to be 0.49 million gallons per day (figure 38.3.c).

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Shelbina Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on June 20, 2001. Surface area of the lake and associated storage volume capacities are illustrated in figure 38.4.

Shelbina Reservoir Physical Data

Shelbina Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-feet)	
700.0	4.09	4.27	
702.0	9.93	18.04	
704.0	15.35	42.73	
706.0	22.75	80.69	
708.0	27.97	131.64	
710.0	36.73	194.48	
712.0	41.50	273.75	
714.0	44.97	360.17	
714.3	45.68	373.75	Lake Condition on June 20, 2001
715.0	47.06	406.25	Spillway
716.0	53.66	457.67	
718.0	63.75	575.31	
720.0	81.92	717.84	Top of Dam

[LIMITS]

Maximum storage……………………………………………………………406 acre-feet
Minimum storage…………………………………………………………………10 acre-feet
Drainage basin size……………………………………………………….2.41 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period for this model is January 1951 through 1959.

[SEEPAGE]

Seepage from Shelbina Reservoir is estimated to be approximately 2.5 inches per month when at or near full capacity and approaches 0.0 as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials – seepage through the dam is considered negligible.

[RAINFALL]

Precipitation values for the drought of record were obtained from Shelbina, Missouri.

Average precipitation in Shelbina is 37.2 inches. The most severe drought occurred between 1953 and 1957 with annual precipitation values in Shelbina of 24.1, 33.6, 39.4, 27.88, and 42.38 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the North River stream gauge at Bethel. The drainage area monitored by this stream gauge covers approximately 58.0 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Shelbina, individual storm events were considered. Antecedent moisture was determined for each storm event and adjustments to the Natural Resource Conservation

Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Shelbina Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at New Franklin, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

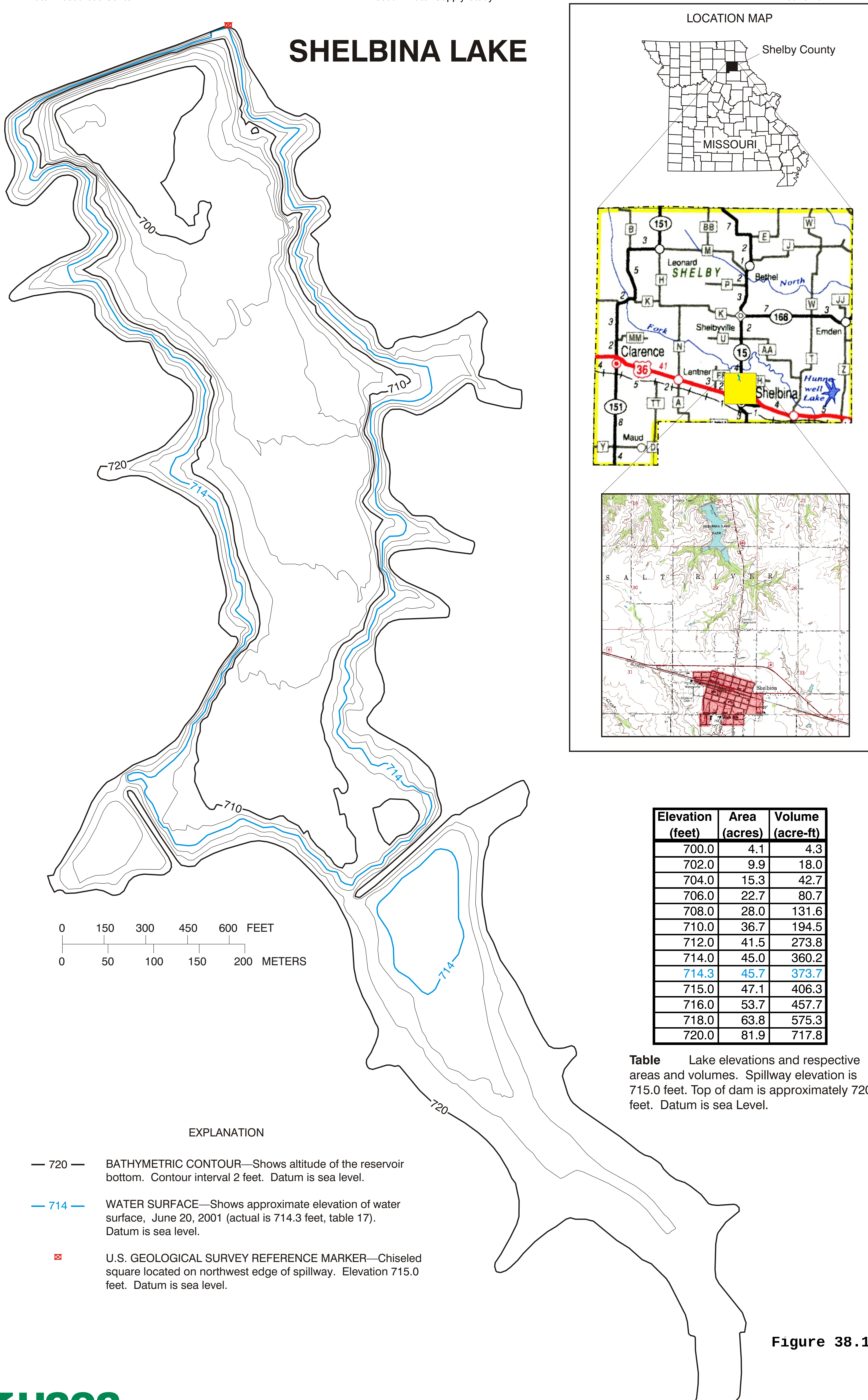
Demand used in this analysis is 0.35 million gallons per day.

Water demand was obtained from records reported by the city to Missouri Department of Natural Resources "Major Water Users Data Base". Their water use has been unsteady. In 1989 they reported using 0.50 million gallons per day and in 2001 they reported 0.36 million gallons per day. For this evaluation a mid-point demand of 0.35 million gallons per day was assumed. During this 13 years of data, demand trend has steadily decreased by an average of 11,700 gallons per day.

[OTHER]

Other is the gain or loss from sources other than the above control words. For the months that water was needed to keep Shelbina Reservoir storage at maximum capacity, a 600 gallons per minute pump was installed on Salt River. There is an 8-inch pipeline with a 30 horsepower pump that is about 0.75 miles long to pump water to the lake. To assure adequate downstream flow in Salt River, two sets of data were examined. The 7-day duration 10-year frequency low flow for the period 1989 through 1999 was studied for in-stream flow needs and this value was determined to be 2 cubic feet second. For the first analyses, a stream flow rate of 23 cubic feet per second was chosen and the second analysis included using 2 cubic feet per second and pumping to the lake beginning near the spillway elevation.

SHELBINA LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
700.0	4.1	4.3
702.0	9.9	18.0
704.0	15.3	42.7
706.0	22.7	80.7
708.0	28.0	131.6
710.0	36.7	194.5
712.0	41.5	273.8
714.0	45.0	360.2
714.3	45.7	373.7
715.0	47.1	406.3
716.0	53.7	457.7
718.0	63.8	575.3
720.0	81.9	717.8

Table Lake elevations and respective areas and volumes. Spillway elevation is 715.0 feet. Top of dam is approximately 720 feet. Datum is sea Level.

EXPLANATION

— 720 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Datum is sea level.

— 714 — WATER SURFACE—Shows approximate elevation of water surface, June 20, 2001 (actual is 714.3 feet, table 17). Datum is sea level.

⊠ U.S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled square located on northwest edge of spillway. Elevation 715.0 feet. Datum is sea level.

Figure 38.1

USGS
science for a changing world

Bathymetric map and table of areas/volumes of Shelbina Lake near Shelbina, Missouri.

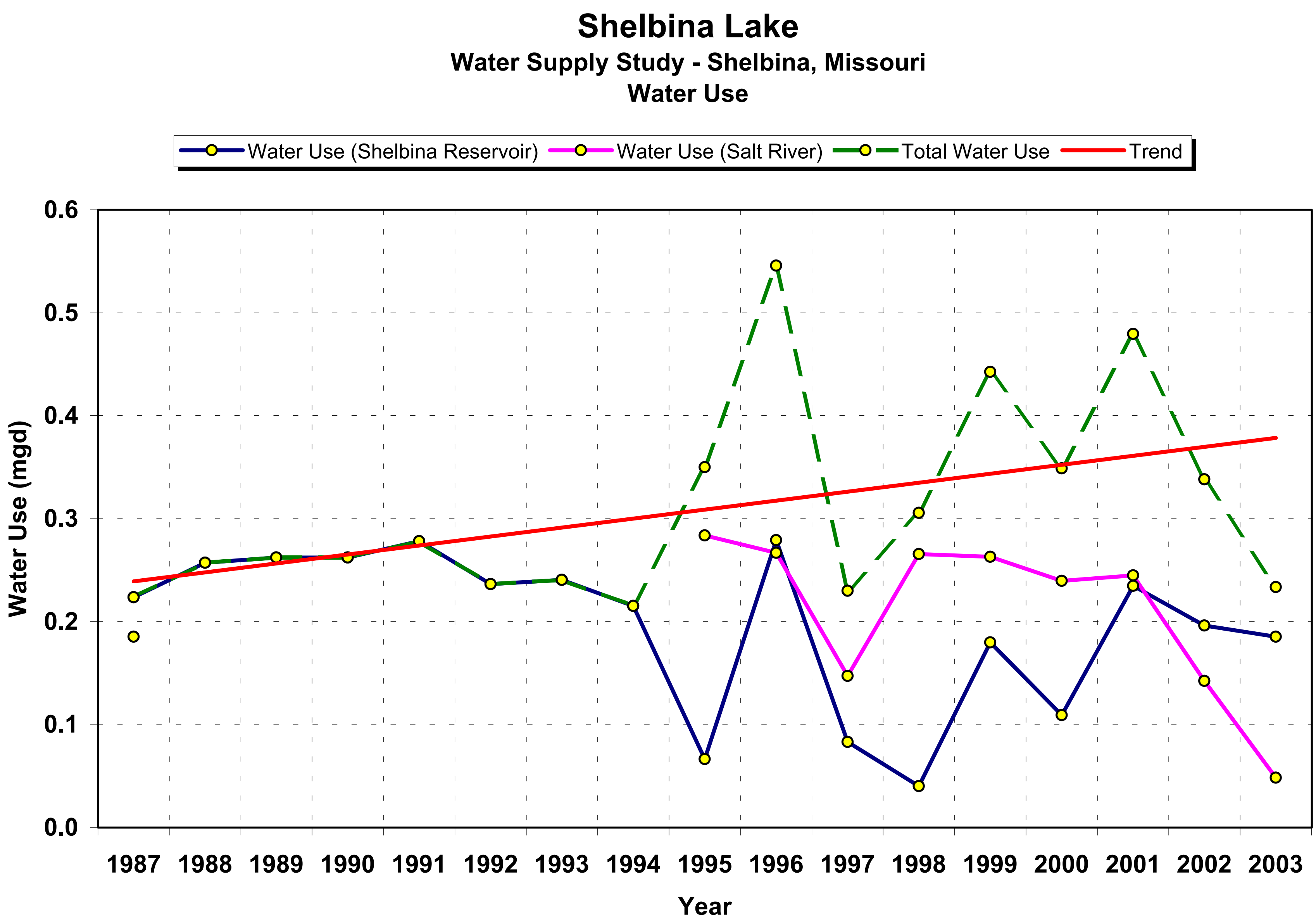

Shelbina Lake
Water Supply Study - Shelbina, Missouri
Water Use
Water Use (Shelbina Reservoir)
Water Use (Salt River)
Total Water Use
Trend
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Water Use (mgd)
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Year

Figure 38.2

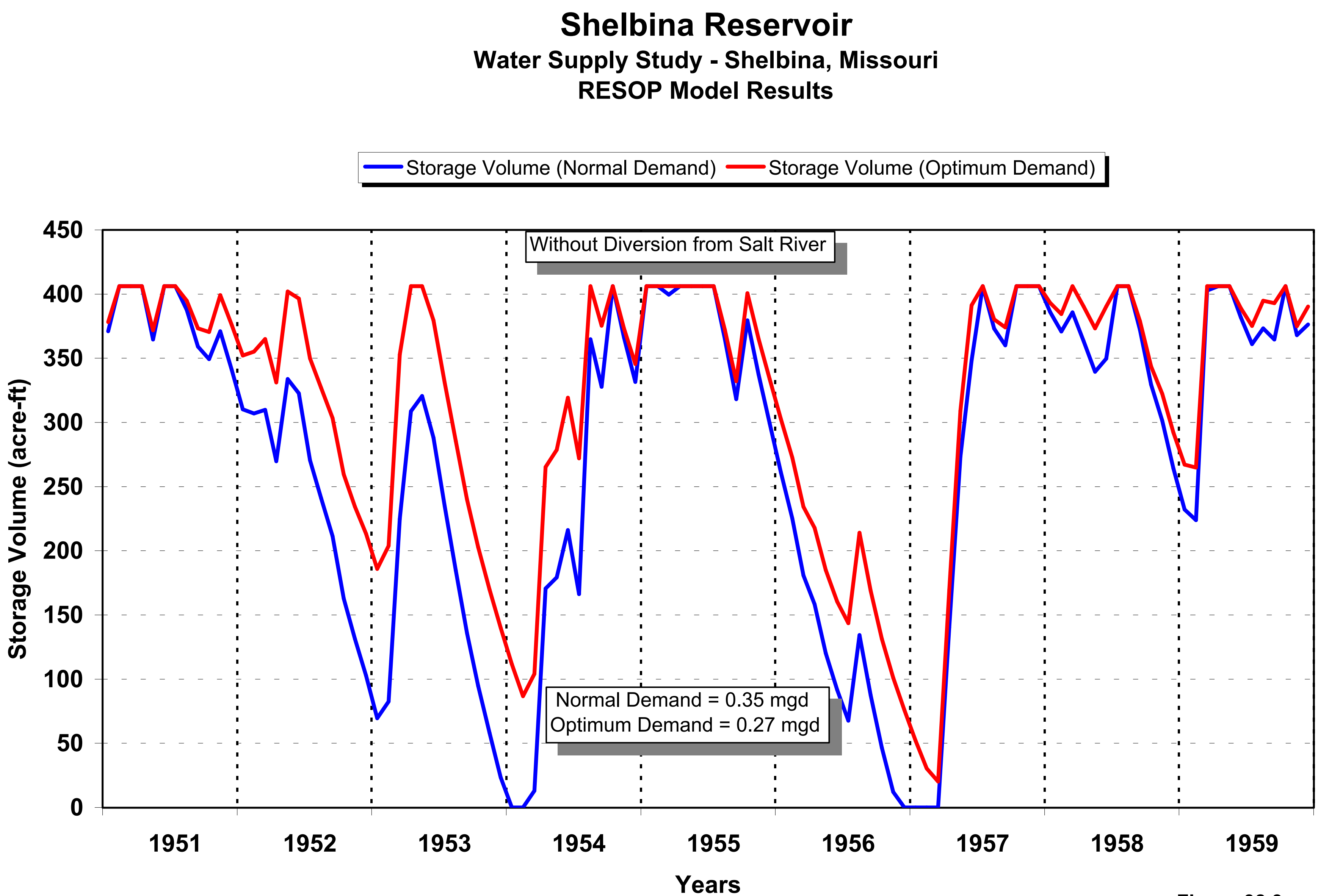

Shelbina Reservoir
Water Supply Study - Shelbina, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Without Diversion from Salt River
Normal Demand = 0.35 mgd
Optimum Demand = 0.27 mgd
Storage Volume (acre-ft)
450
400
350
300
250
200
150
100
50
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 38.3.a

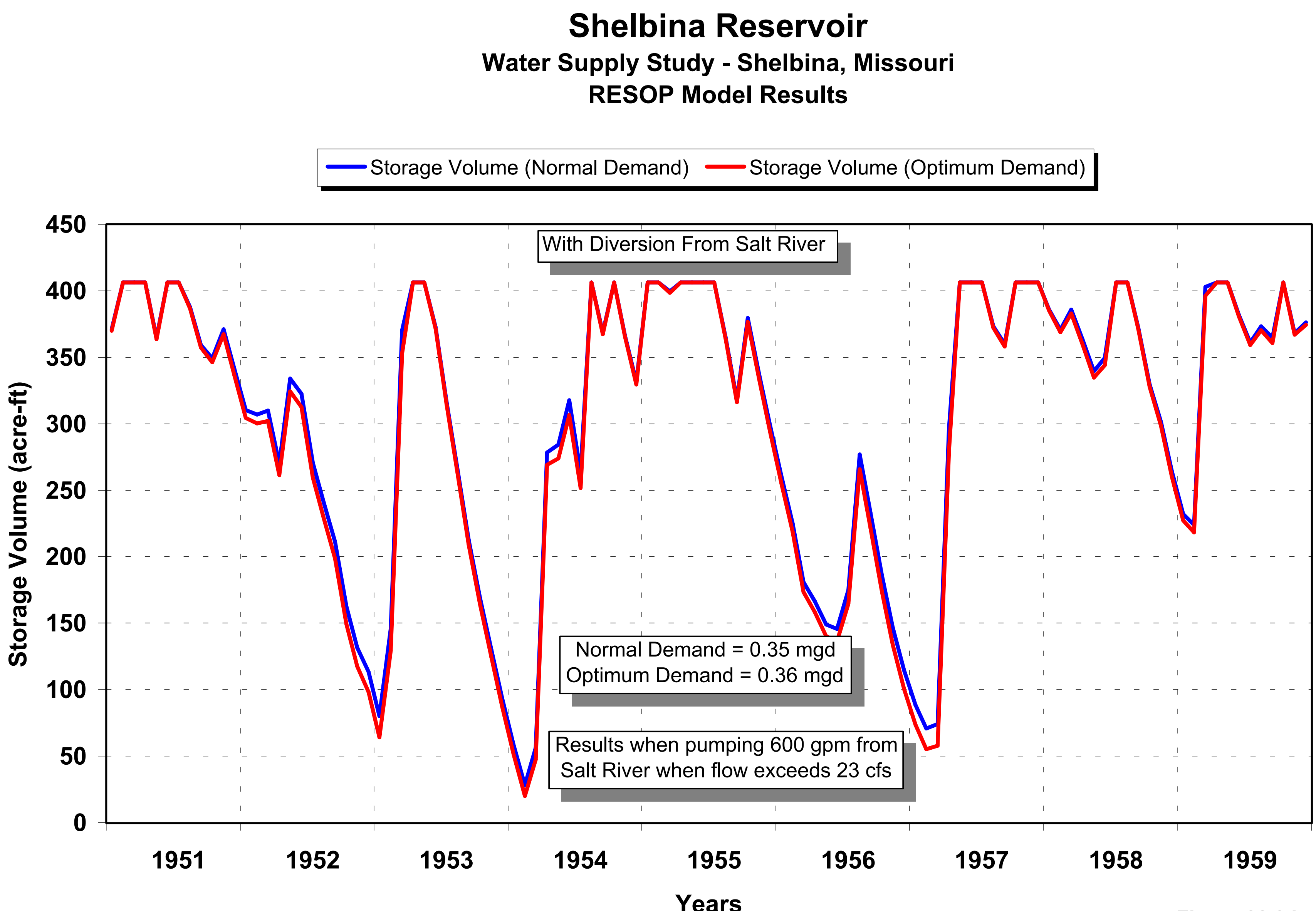

Shelbina Reservoir
Water Supply Study - Shelbina, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
With Diversion From Salt River
Normal Demand = 0.35 mgd
Optimum Demand = 0.36 mgd
Results when pumping 600 gpm from
Salt River when flow exceeds 23 cfs
Storage Volume (acre-ft)
450
400
350
300
250
200
150
100
50
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 38.3.b

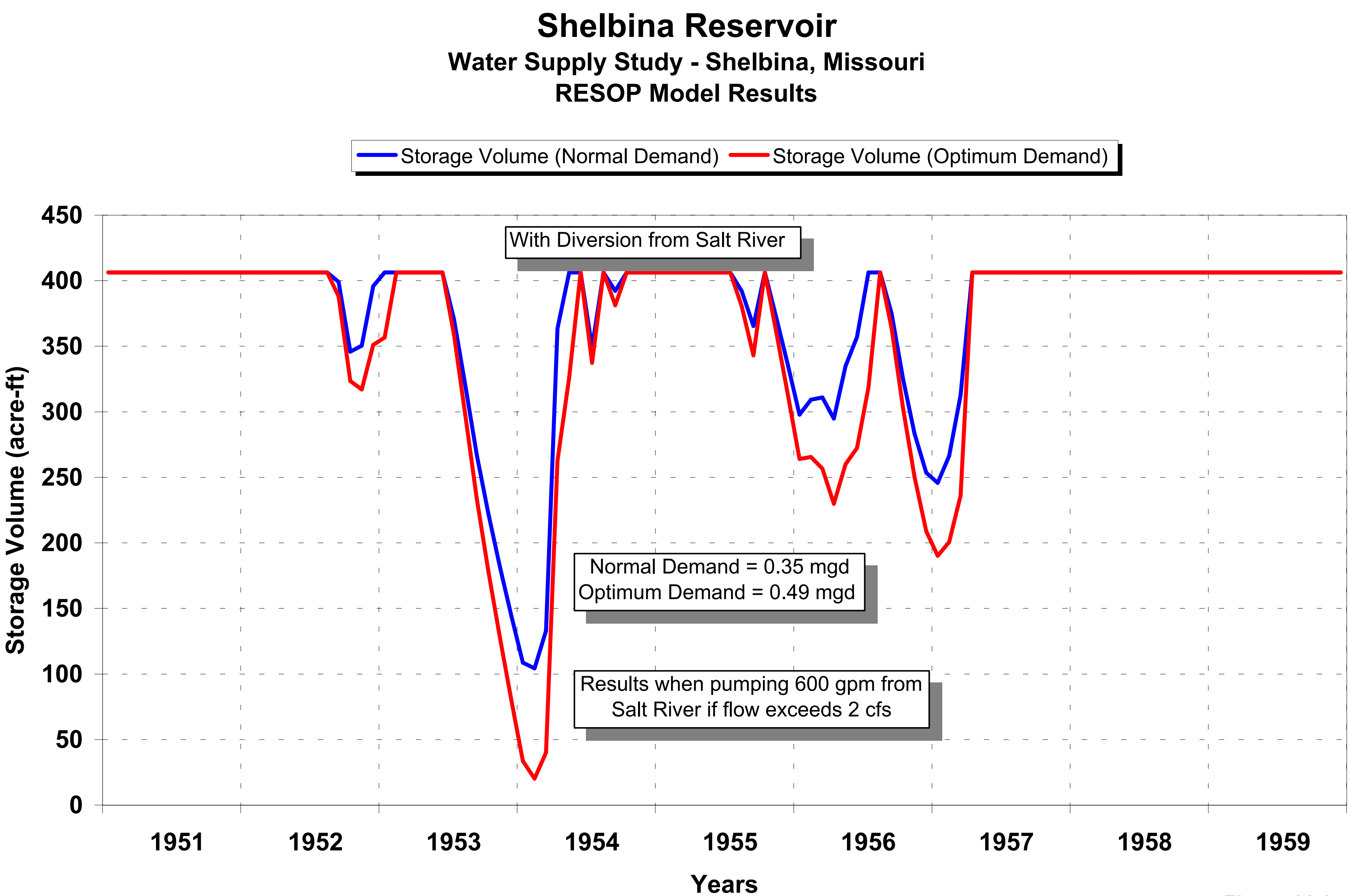

Shelbina Reservoir
Water Supply Study - Shelbina, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
With Diversion from Salt River
Normal Demand = 0.35 mgd
Optimum Demand = 0.49 mgd
Results when pumping 600 gpm from Salt River if flow exceeds 2 cfs
Storage Volume (acre-ft)
450
400
350
300
250
200
150
100
50
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

Figure 38.3.c

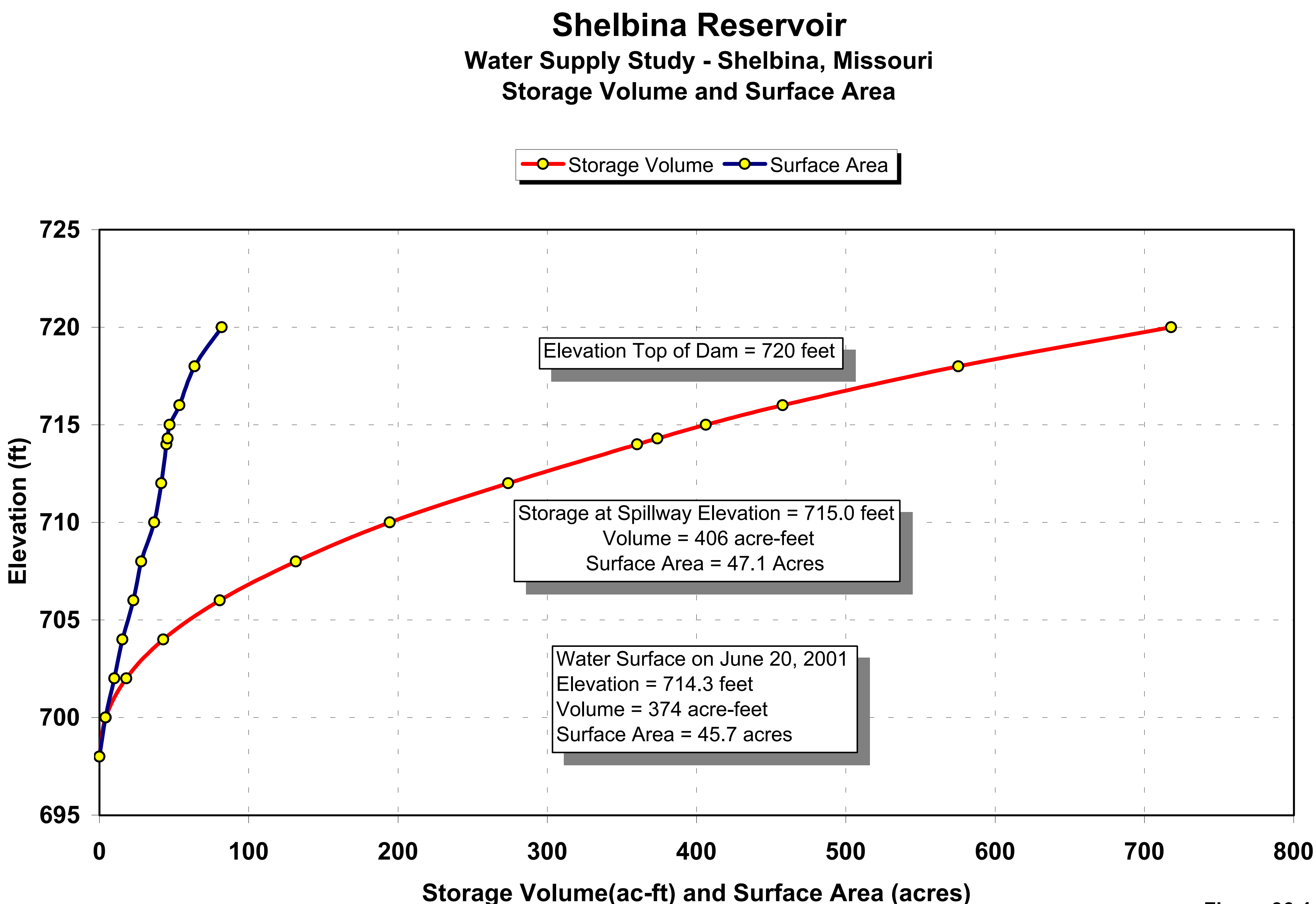

Shelbina Reservoir
Water Supply Study - Shelbina, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Elevation Top of Dam = 720 feet
Storage at Spillway Elevation = 715.0 feet
Volume = 406 acre-feet
Surface Area = 47.1 Acres
Water Surface on June 20, 2001
Elevation = 714.3 feet
Volume = 374 acre-feet
Surface Area = 45.7 acres
Elevation (ft)
725
720
715
710
705
700
695
0
100
200
300
400
500
600
700
800
Storage Volume(ac-ft) and Surface Area (acres)

Figure 36.4

Lake Mahoney and Lake Thunderhead
Water Supply Study – Unionville, Missouri
Drought Assessment Analysis

I. Overview

Lake Mahoney (figure 39.1.a) and Lake Thunderhead (figure 39.1.b) are located in central Putnam County in North Central Missouri. Lake Mahoney is located upstream of Lake Thunderhead. Both reservoirs are on Wildcat Creek. Lake Mahoney provides Unionville with their water supply. Lake Thunderhead is a privately owned lake and is not designed as a water supply reservoir, however it has the capabilities of providing supplemental water supply during periods of extreme droughts. Lake Mahoney is located 2 miles North of Unionville with a drainage area of 2.97 square miles and Lake Thunderhead is located 5 miles north of Unionville having an incremental drainage area of 22.96 square miles for a total drainage area of 25.93 square miles.

Unionville demand is met by Lake Mahoney Reservoir but must be supplemented with water from Lake Thunderhead during extended periods of drought. Unionville draws water directly from the lakes to the treatment plant. Demand on the system is 0.38 million gallons per day in year 2000. Historical water demand on the Lake Mahoney and Lake Thunderhead Reservoirs is illustrated in figure 39.2. Unionville's water demand has remained constant from 1987 through 2003. Unionville supplies water to Putnam County Public Water Supply District #1 and Lake Thunderhead community.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Three scenarios were modeled for Lake Mahoney and Lake Thunderhead.

The first scenario modeled Lake Mahoney with Unionville's normal demand of 0.38 million gallons per day. The optimum demand from Lake Mahoney is 0.28 million gallons per day. Water withdraw from Lake Thunderhead was not considered for this option (figure 39.3.a).

The second scenario modeled Lake Thunderhead with Unionville's normal demand with 0.38 million gallons per day. The optimum demand from Lake Thunderhead is 3.36 million gallons per day. Water withdraw from Lake Mahoney was not considered for this option (figure 39.3.b).

The third scenario modeled Lake Thunderhead comparing three different options. Option one displays the normal demand for Unionville from Lake Thunderhead with no input from Lake Mahoney. Option two displays the effect on Lake Thunderhead with optimum demand of 0.28 million gallons per day from Lake Mahoney and none from Lake Thunderhead. The third option modeled displays effects on Lake Thunderhead when Lake Mahoney provides 0.28 million gallons per day and Lake Thunderhead provides 0.10 million gallons per day to provide for normal demand of 0.38 million gallons per day (figure 39.3.c). Figure 39.3.d displays figure 39.3.c in terms of elevation over time to demonstrate effects on water elevation.

II. Drought Assessment Summary

The Lake Mahoney reservoir is at risk of not meeting the community's demand for water during times of drought. The year 2000 demand on the reservoir was approximately 0.38 million gallons per day, and when this demand value is applied to the reservoir during the drought of record in

the 1950’s, water deficits would have occurred from January 1956 until April 1958. The estimated optimum yield from Lake Mahoney Reservoir is 0.28 million gallons per day (figure 39.3.a).

Lake Thunderhead is capable of supplementing the water shortage. Lake Thunderhead Modeling shows that the reservoir could provide 0.38 million gallons per day with 12,700 acre-feet remaining in the lake at elevation 963.8 feet or 5.5 feet below the spillway. If Unionville’s demand of 0.38 million gallons per day were met by Lake Mahoney’s optimum demand of 0.28 million gallons per day an 0.10 million gallons per day from Lake Thunderhead, Lake Thunderhead water level would be at elevation 964.2 feet with 12,500 acre-feet remaining in the reservoir. Figures 39.3.b through 39.3.d shows these results. Figure 39.3.e represents reduction of water storage in Lake Thunderhead when optimum demand was applied to both Lake Thunderhead and Lake Mahoney.

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to ‘control words’ for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from bathymetric surveys of Lake Mahoney and Lake Thunderhead conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources. On April 6, 2004 for Lake Mahoney was surveyed and Lake Thunderhead was surveyed March 29 through April 3, 2004. Surface area of the lakes and associated storage volume capacities are illustrated in figure 39.4.a and 39.4.b.

Lake Mahoney and Lake Thunderhead Physical Data

Lake Mahoney				***Lake Thunderhead***		
959.0	1.1	0.3		932.0	16.8	10.1
961.0	7.4	8.5		934.0	48.7	76.5
963.0	14.4	30.2		936.0	78.0	202
965.0	21.8	66.2		938.0	118	398
967.0	31.1	120		940.0	162	678
969.0	39.1	190		942.0	208	1,050
971.0	45.9	270		944.0	260	1,510
973.0	52.5	370		946.0	304	2,080
975.0	60.1	490		948.0	356	2,740
977.0	72.3	620		950.0	412	3,500
977.3	75.5	640		952.0	476	4,390
979.0	98.0	790		954.0	537	5,400
981.0	129	1,020		956.0	598	6,540
985.0	154	1,580		958.0	660	7,800
987.0	168	1,900		960.0	721	9,180
989.0	183	2,250		962.0	791	10,690
989.5	187	2,360		964.0	864	12,340
				966.0	940	14,140
				967.3	989	15,400
				967.8	1,010	15,900
				968.0	1,040	16,100
				970.0	1,100	18,240
				971.3	1,140	19,690

Elevation Top of Dam = 989.5 feet Elevation Spillway = 977.0 feet Lake Condition on April 6, 2004 Elevation = 977.3 feet	Elevation Top of Dam = 971.3 feet Elevation Spillway = 967.3 feet Lake Condition on April 6, 2004 Elevation = 967.8 feet

[LIMITS]

Lake Mahoney

Maximum storage ....620 acre-feet
Minimum storage ....120 acre-feet
Drainage basin size .... 2.97 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

Lake Thunderhead

Maximum storage ....15,400 acre-feet
Minimum storage ....1,500 acre-feet
Drainage basin size .... 22.96 square miles
Total basin size including Lake Mahoney…………………………….25.93 square miles

Initial storage volume was equated to the reservoir volume at maximum capacity.

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1959.

[SEEPAGE]

Seepage from Lake Mahoney is approximately 1.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. Seepage from Lake Thunderhead is approximately 3.0 inches per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoirs are bound by earthen dams composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Average precipitation at Unionville was 36.6 inches between 1950 and 1993. Precipitation values for the drought of record were obtained from Unionville, Missouri. The most severe drought occurred between 1953 and 1957 with annual precipitation values in Unionville of 24.1, 33.6, 39.4, 27.88, and 47.1 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Locust Creek stream gauge at Linneus. The drainage area monitored by this stream gauge covers approximately 550 square miles.

Monthly runoff volumes in watershed inches were determined and comparisons were made for the Locust Creek River Gauge at Linneus, Medicine Creek near Galt, and South Fork Chariton River near Promise, Iowa. The three gauges yielded similar monthly runoff volumes. The South Fork Chariton River gauge did not have enough years of data to evaluate the drought of record.

After these comparisons, Locust Creek gauge was chosen to represent runoff for the watershed.

When these regional runoff values are inconsistent with precipitation values recorded for Unionville, individual storm events were considered. Antecedent rainfall was determined for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information)

[EVAP.]

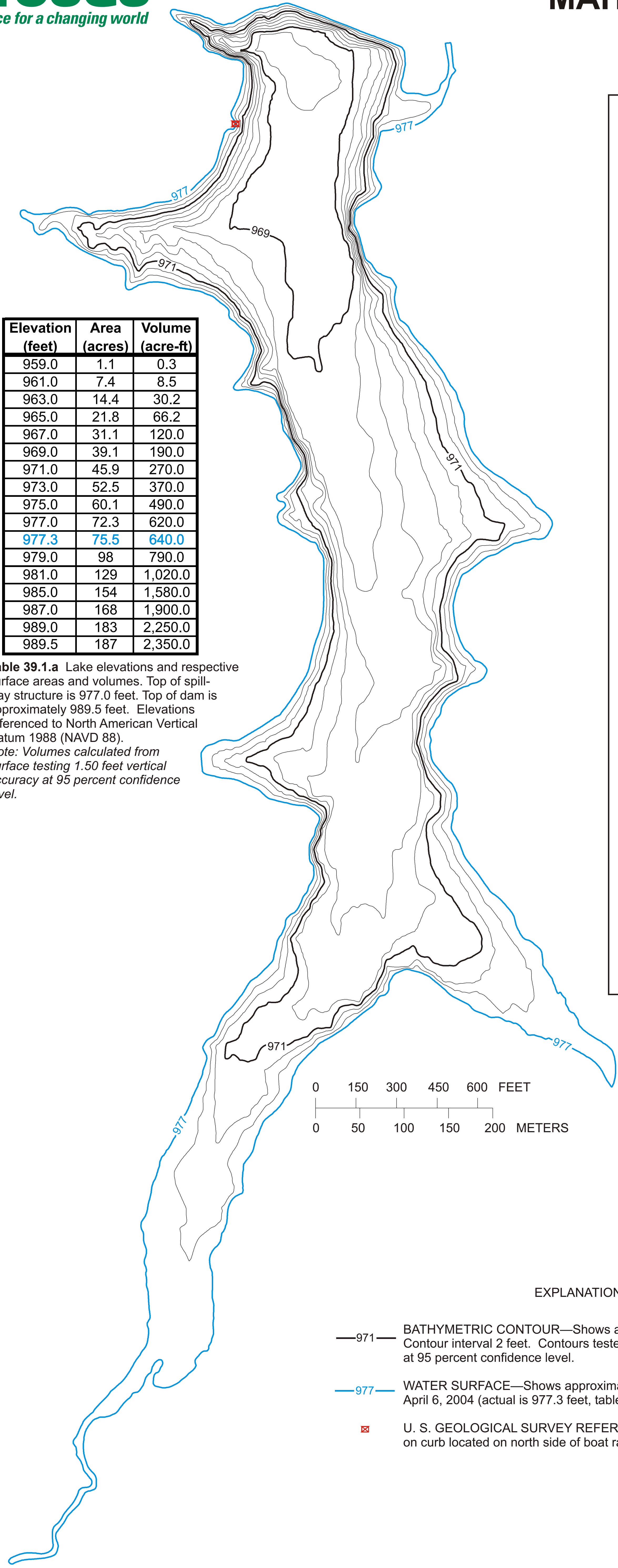
Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Lake Mahoney and Lake Thunderhead due to evaporation. This data was supplemented and compared with evaporation data from stations at Spickard, Missouri, New Franklin, Missouri, or Columbia, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan to lake evaporation.

[DEMAND]

The year 2000 demand was used for this evaluation and was reported to be an average of 0.38 million gallons per day.

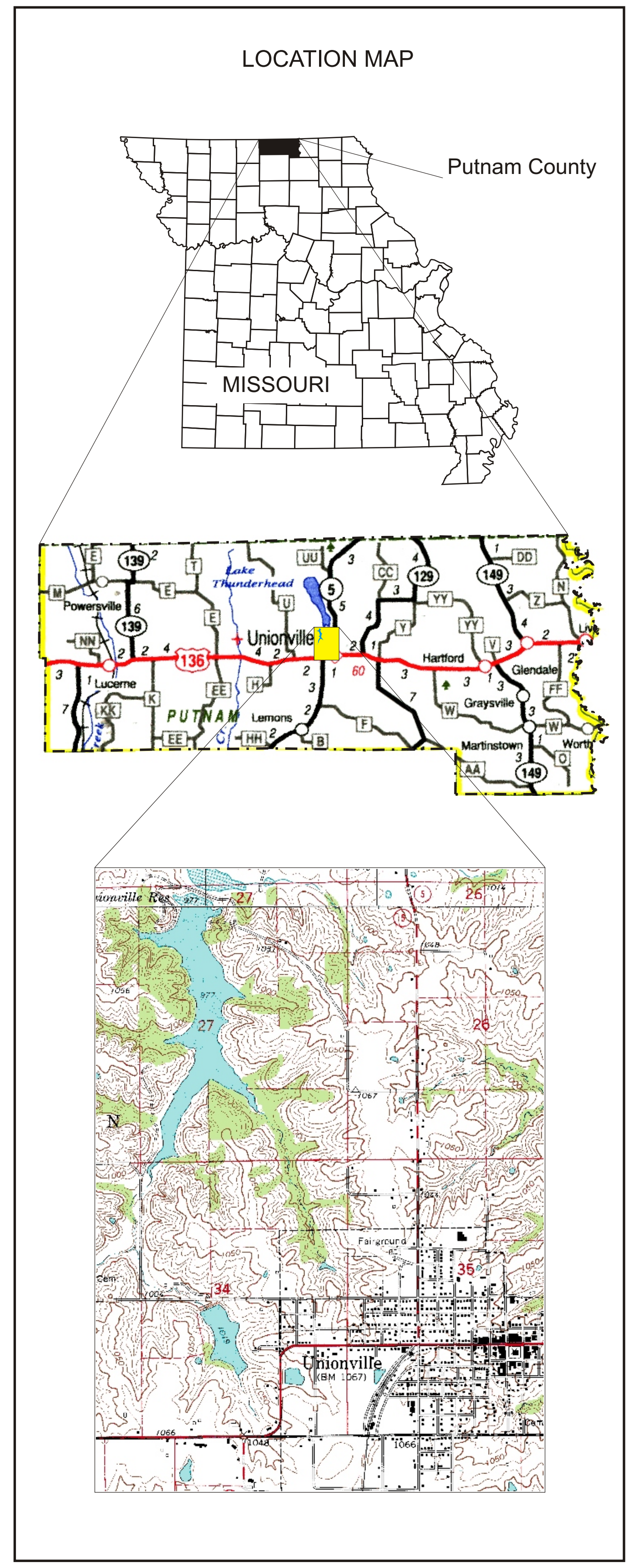
Water demand was obtained from records reported by the city of Unionville, to Missouri Department of Natural Resources "Major Water Users Data Base". Unionville began reporting their water use in 1987. Their water use fluctuates but is reasonably steady. In 1994 they reported using a high of 155,584,000 gallons and in 1997 was the low usage of 115,000,000 gallons.

MAHONEY LAKE



Elevation (feet)	Area (acres)	Volume (acre-ft)
959.0	1.1	0.3
961.0	7.4	8.5
963.0	14.4	30.2
965.0	21.8	66.2
967.0	31.1	120.0
969.0	39.1	190.0
971.0	45.9	270.0
973.0	52.5	370.0
975.0	60.1	490.0
977.0	72.3	620.0
977.3	75.5	640.0
979.0	98	790.0
981.0	129	1,020.0
985.0	154	1,580.0
987.0	168	1,900.0
989.0	183	2,250.0
989.5	187	2,350.0

Table 39.1.a Lake elevations and respective surface areas and volumes. Top of spillway structure is 977.0 feet. Top of dam is approximately 989.5 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.50 feet vertical accuracy at 95 percent confidence level.



EXPLANATION

971 BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Contours tested 2.47 feet vertical accuracy at 95 percent confidence level.

977 WATER SURFACE—Shows approximate elevation of water surface, April 6, 2004 (actual is 977.3 feet, table 33).

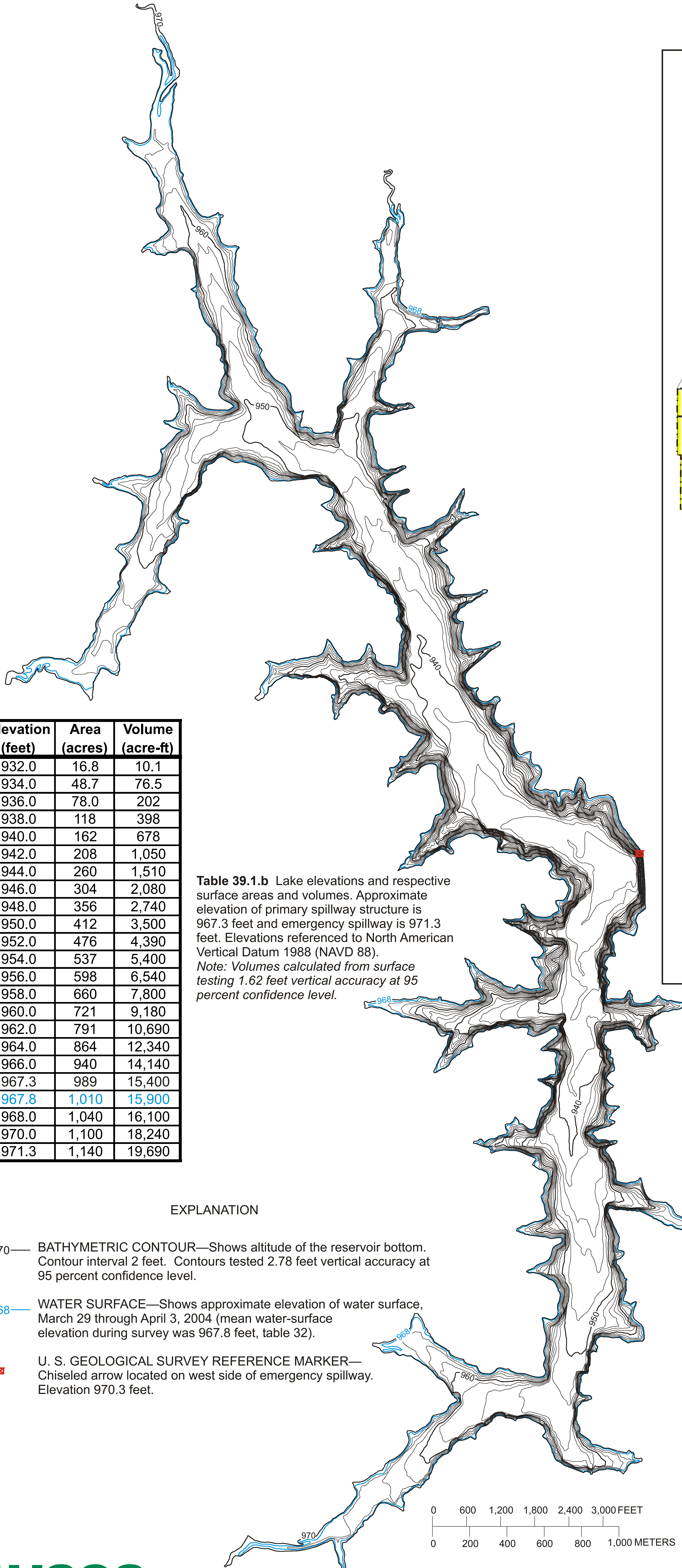
U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow on curb located on north side of boat ramp. Elevation 977.4 feet.

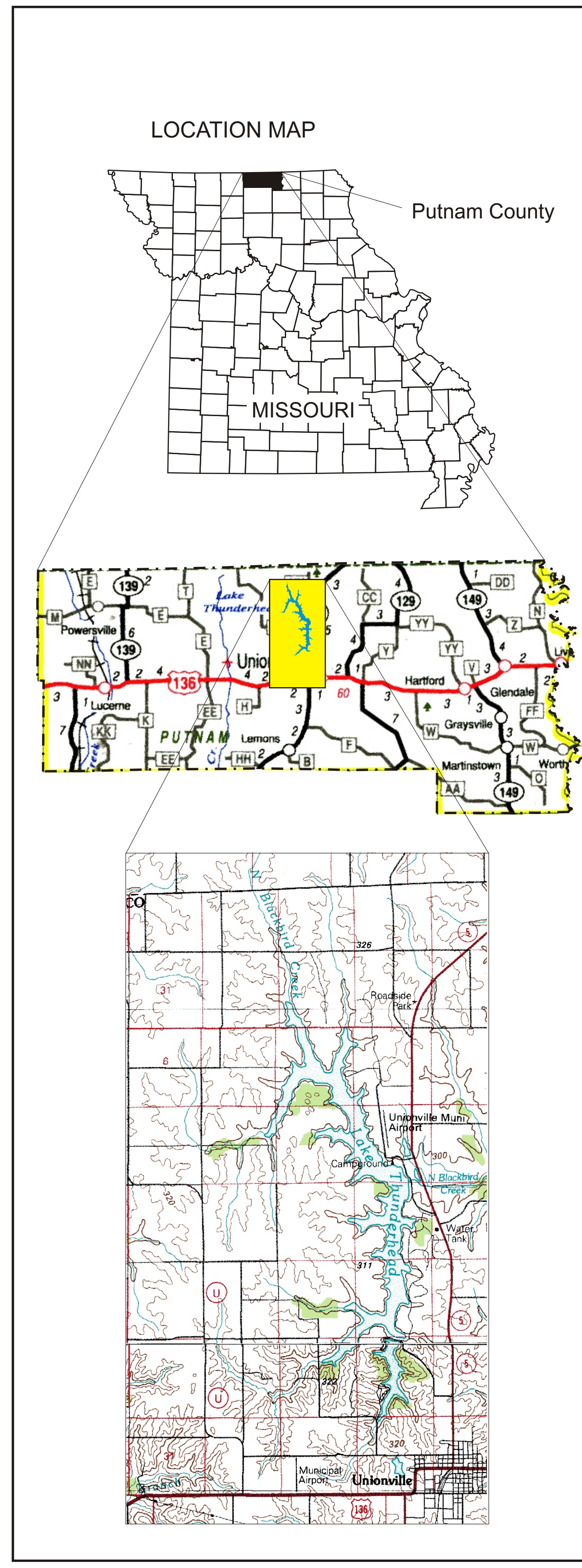
Figure 39.1.a

Figure 39.1.a Bathymetric map and table of areas/volumes of the Mahoney Lake near Unionville, Missouri.

In cooperation with Missouri Department of Natural Resources

THUNDERHEAD LAKE





Elevation (feet)	Area (acres)	Volume (acre-ft)
932.0	16.8	10.1
934.0	48.7	76.5
936.0	78.0	202
938.0	118	398
940.0	162	678
942.0	208	1,050
944.0	260	1,510
946.0	304	2,080
948.0	356	2,740
950.0	412	3,500
952.0	476	4,390
954.0	537	5,400
956.0	598	6,540
958.0	660	7,800
960.0	721	9,180
962.0	791	10,690
964.0	864	12,340
966.0	940	14,140
967.3	989	15,400
967.8	1,010	15,900
968.0	1,040	16,100
970.0	1,100	18,240
971.3	1,140	19,690

Table 39.1.b Lake elevations and respective surface areas and volumes. Approximate elevation of primary spillway structure is 967.3 feet and emergency spillway is 971.3 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.62 feet vertical accuracy at 95 percent confidence level.

EXPLANATION

——970—— BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Contours tested 2.78 feet vertical accuracy at 95 percent confidence level.

——968—— WATER SURFACE—Shows approximate elevation of water surface, March 29 through April 3, 2004 (mean water-surface elevation during survey was 967.8 feet, table 32).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Chiseled arrow located on west side of emergency spillway. Elevation 970.3 feet.

Figure 39.1.b

Figure 39.1.b Bathymetric map and table of areas/volumes of the Thunderhead Lake near Unionville, Missouri.

In cooperation with Missouri Department of Natural Resources

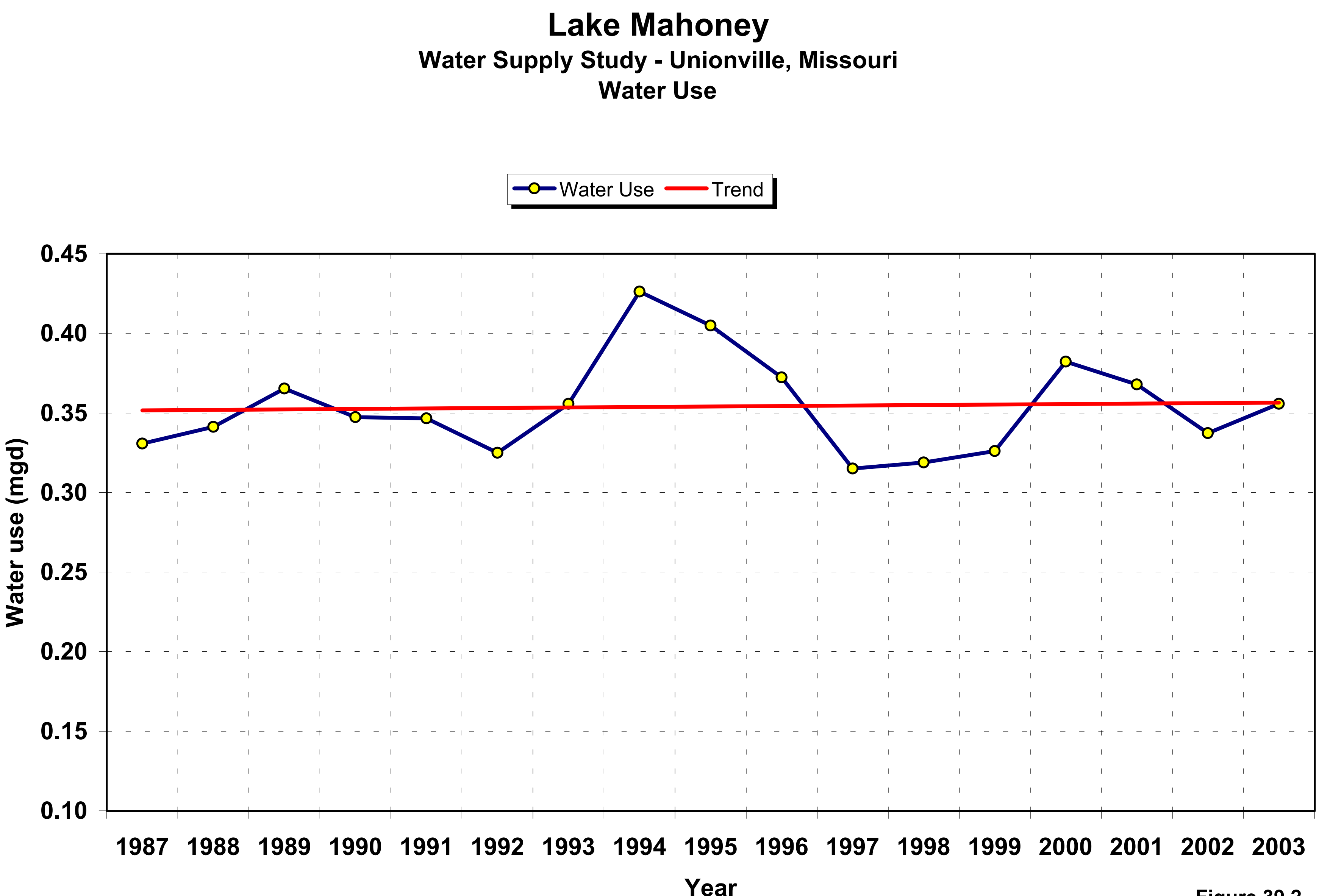

Lake Mahoney
Water Supply Study - Unionville, Missouri
Water Use
Water Use
Trend
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
Water use (mgd)
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003
Year

Figure 39.2

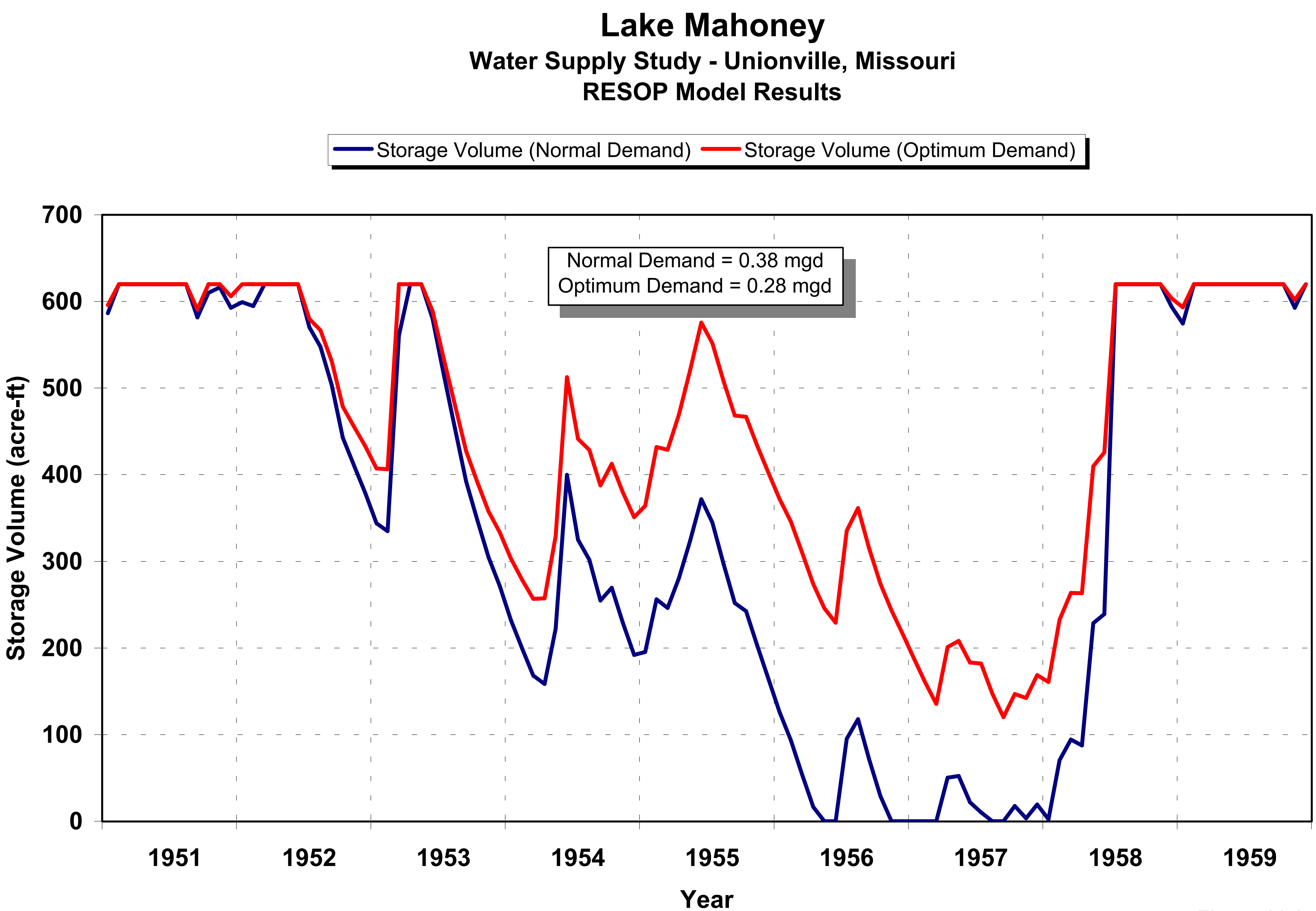

Lake Mahoney
Water Supply Study - Unionville, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Normal Demand = 0.38 mgd
Optimum Demand = 0.28 mgd
Storage Volume (acre-ft)
0
100
200
300
400
500
600
700
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 39.3.a

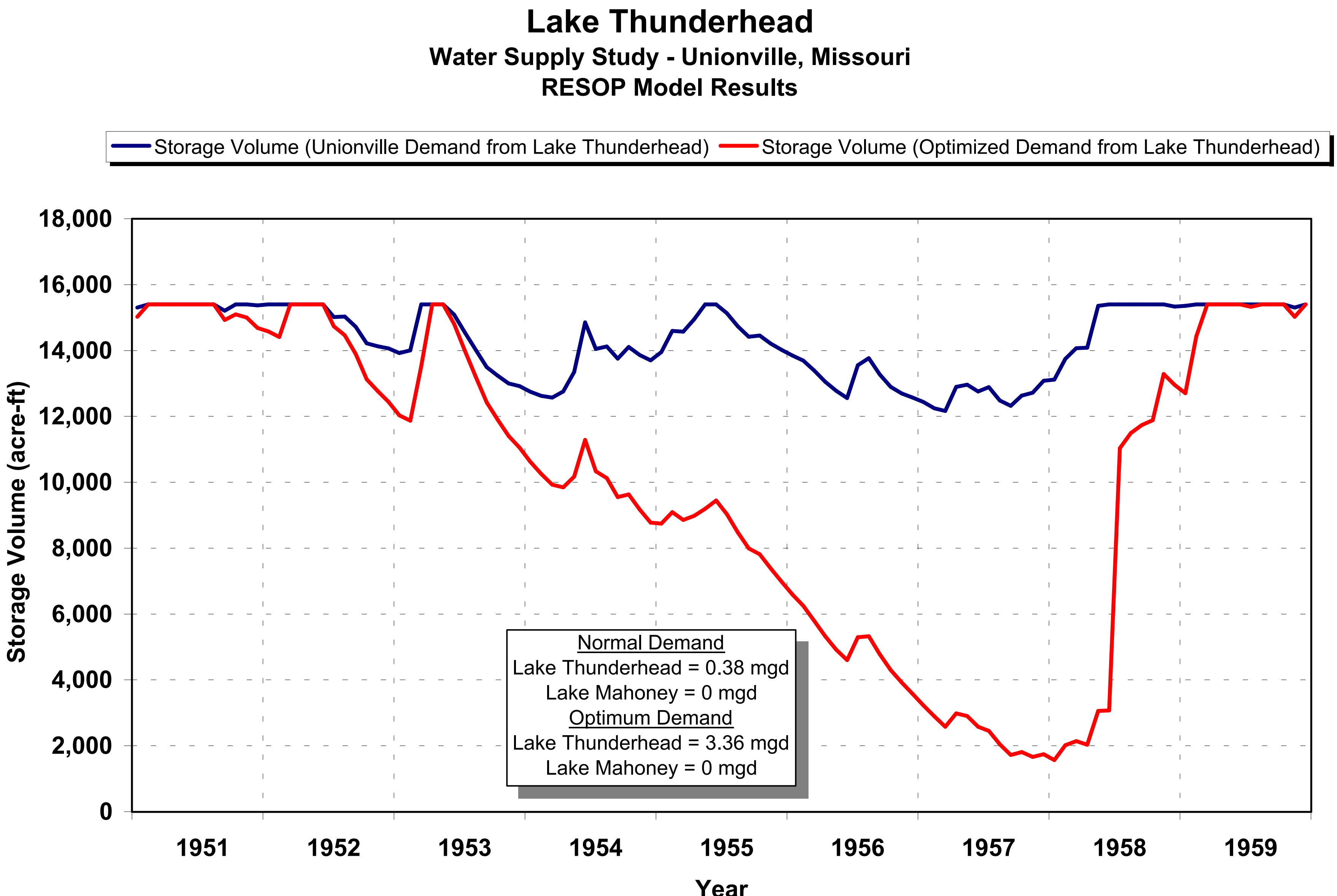

Lake Thunderhead
Water Supply Study - Unionville, Missouri
RESOP Model Results
Storage Volume (Unionville Demand from Lake Thunderhead)
Storage Volume (Optimized Demand from Lake Thunderhead)
Storage Volume (acre-ft)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
Normal Demand
Lake Thunderhead = 0.38 mgd
Lake Mahoney = 0 mgd
Optimum Demand
Lake Thunderhead = 3.36 mgd
Lake Mahoney = 0 mgd

Figure 39.3.b

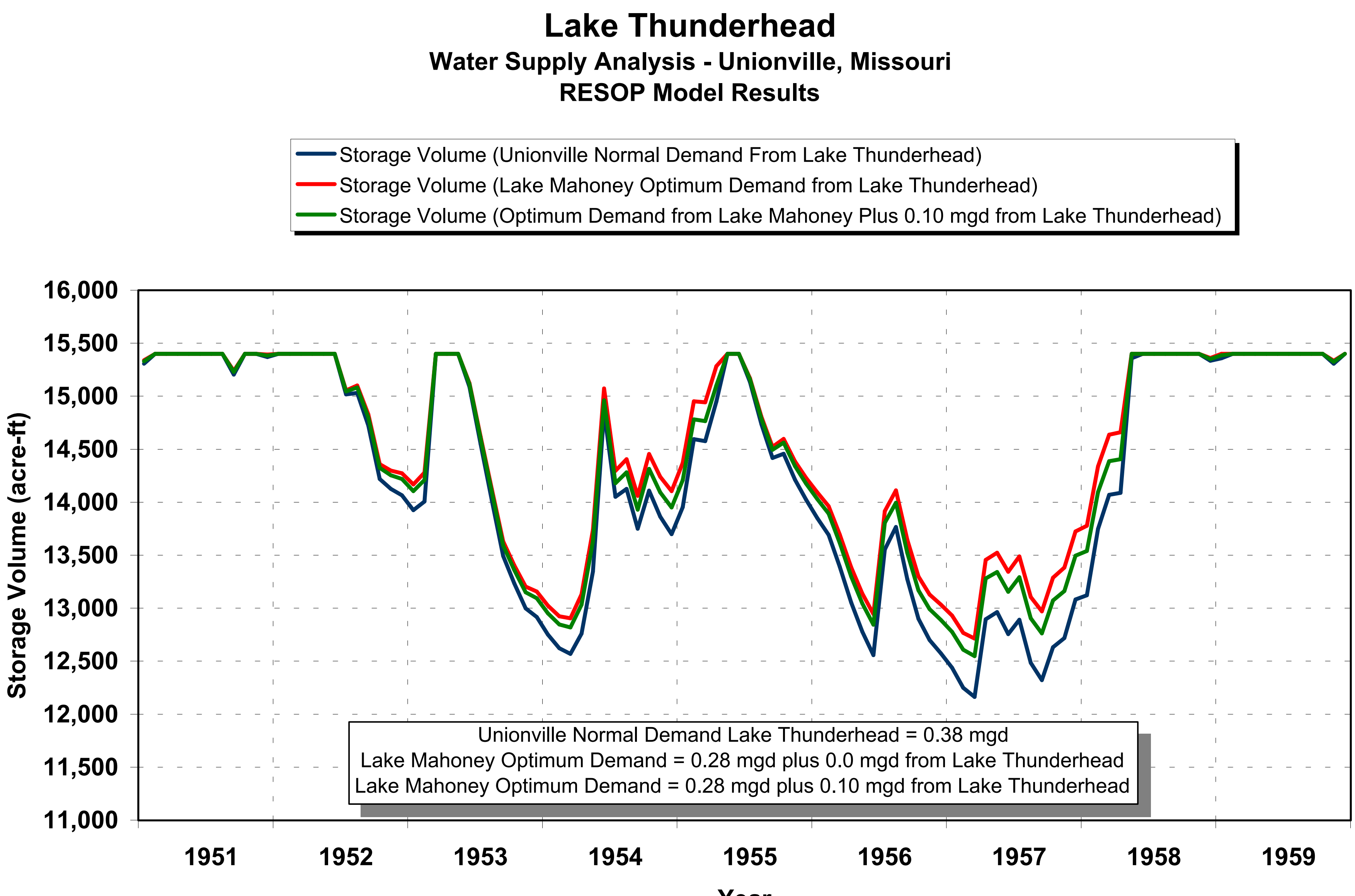

Lake Thunderhead
Water Supply Analysis - Unionville, Missouri
RESOP Model Results
Storage Volume (Unionville Normal Demand From Lake Thunderhead)
Storage Volume (Lake Mahoney Optimum Demand from Lake Thunderhead)
Storage Volume (Optimum Demand from Lake Mahoney Plus 0.10 mgd from Lake Thunderhead)
Storage Volume (acre-ft)
16,000
15,500
15,000
14,500
14,000
13,500
13,000
12,500
12,000
11,500
11,000
Unionville Normal Demand Lake Thunderhead = 0.38 mgd
Lake Mahoney Optimum Demand = 0.28 mgd plus 0.0 mgd from Lake Thunderhead
Lake Mahoney Optimum Demand = 0.28 mgd plus 0.10 mgd from Lake Thunderhead
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 39.3.c

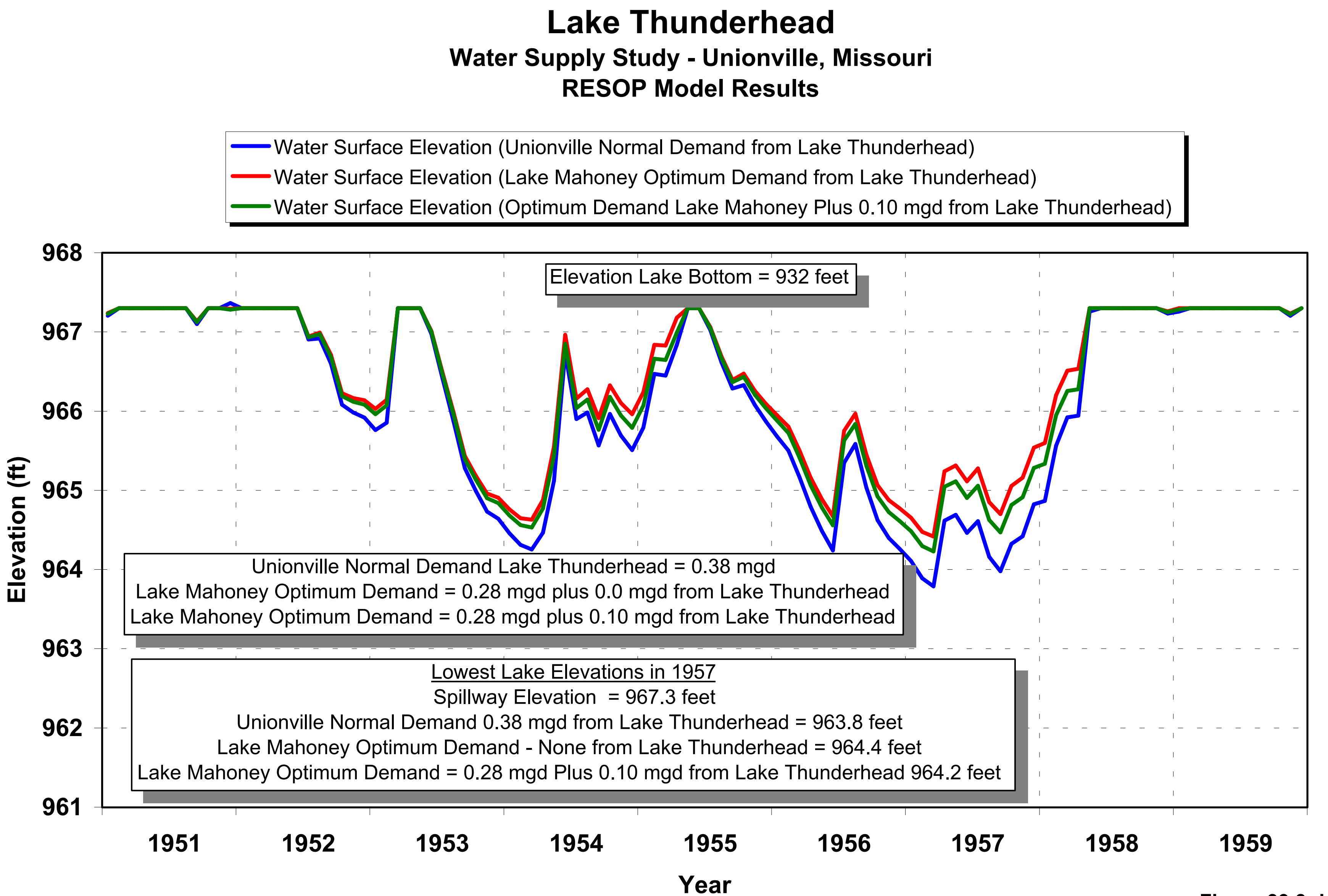

Lake Thunderhead
Water Supply Study - Unionville, Missouri
RESOP Model Results
Water Surface Elevation (Unionville Normal Demand from Lake Thunderhead)
Water Surface Elevation (Lake Mahoney Optimum Demand from Lake Thunderhead)
Water Surface Elevation (Optimum Demand Lake Mahoney Plus 0.10 mgd from Lake Thunderhead)
Elevation Lake Bottom = 932 feet
Unionville Normal Demand Lake Thunderhead = 0.38 mgd
Lake Mahoney Optimum Demand = 0.28 mgd plus 0.0 mgd from Lake Thunderhead
Lake Mahoney Optimum Demand = 0.28 mgd plus 0.10 mgd from Lake Thunderhead
Lowest Lake Elevations in 1957
Spillway Elevation = 967.3 feet
Unionville Normal Demand 0.38 mgd from Lake Thunderhead = 963.8 feet
Lake Mahoney Optimum Demand - None from Lake Thunderhead = 964.4 feet
Lake Mahoney Optimum Demand = 0.28 mgd Plus 0.10 mgd from Lake Thunderhead 964.2 feet
Elevation (ft)
968
967
966
965
964
963
962
961
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 39.3.d

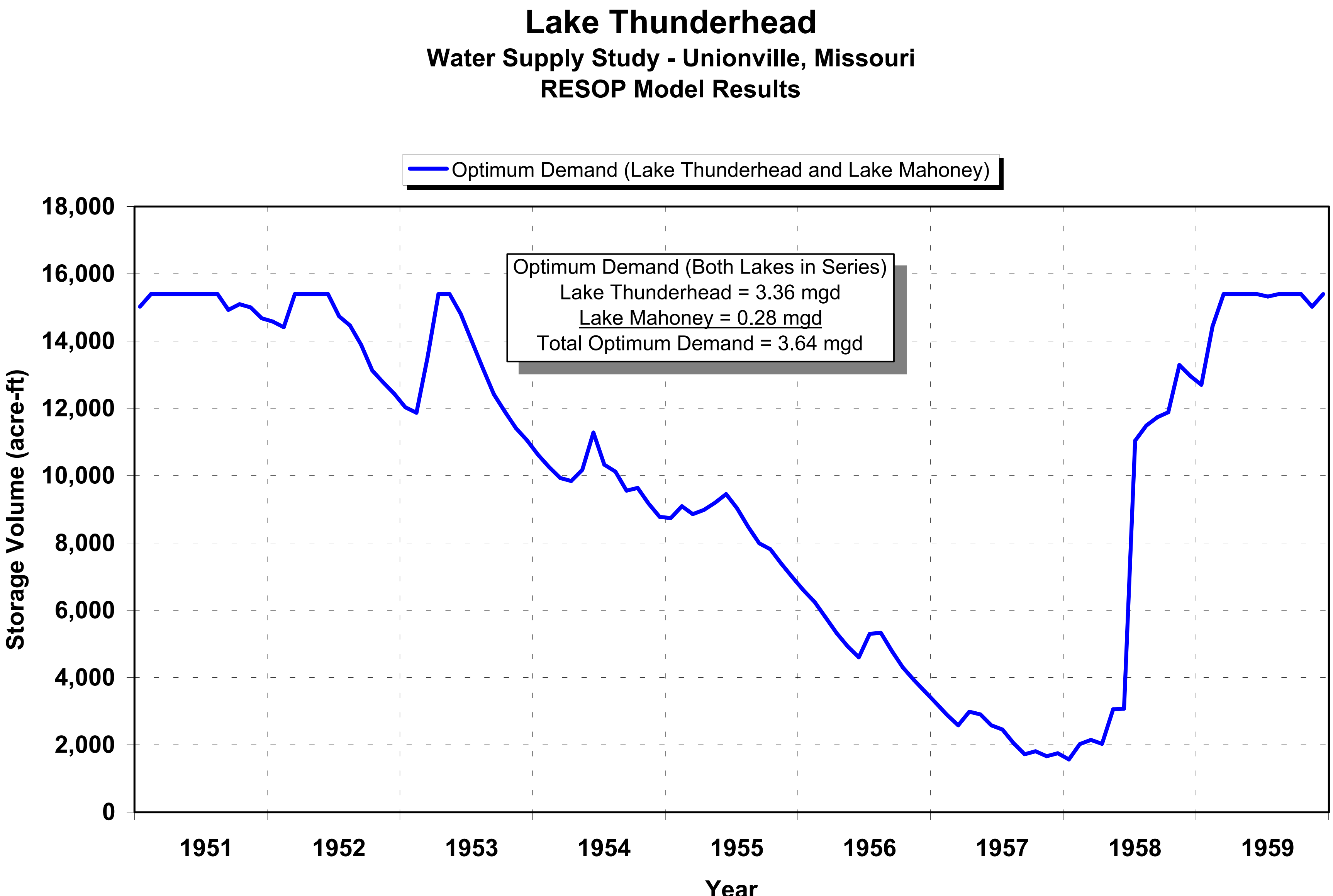

Lake Thunderhead
Water Supply Study - Unionville, Missouri
RESOP Model Results
Optimum Demand (Lake Thunderhead and Lake Mahoney)
Optimum Demand (Both Lakes in Series)
Lake Thunderhead = 3.36 mgd
Lake Mahoney = 0.28 mgd
Total Optimum Demand = 3.64 mgd
Storage Volume (acre-ft)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure 39.3.e

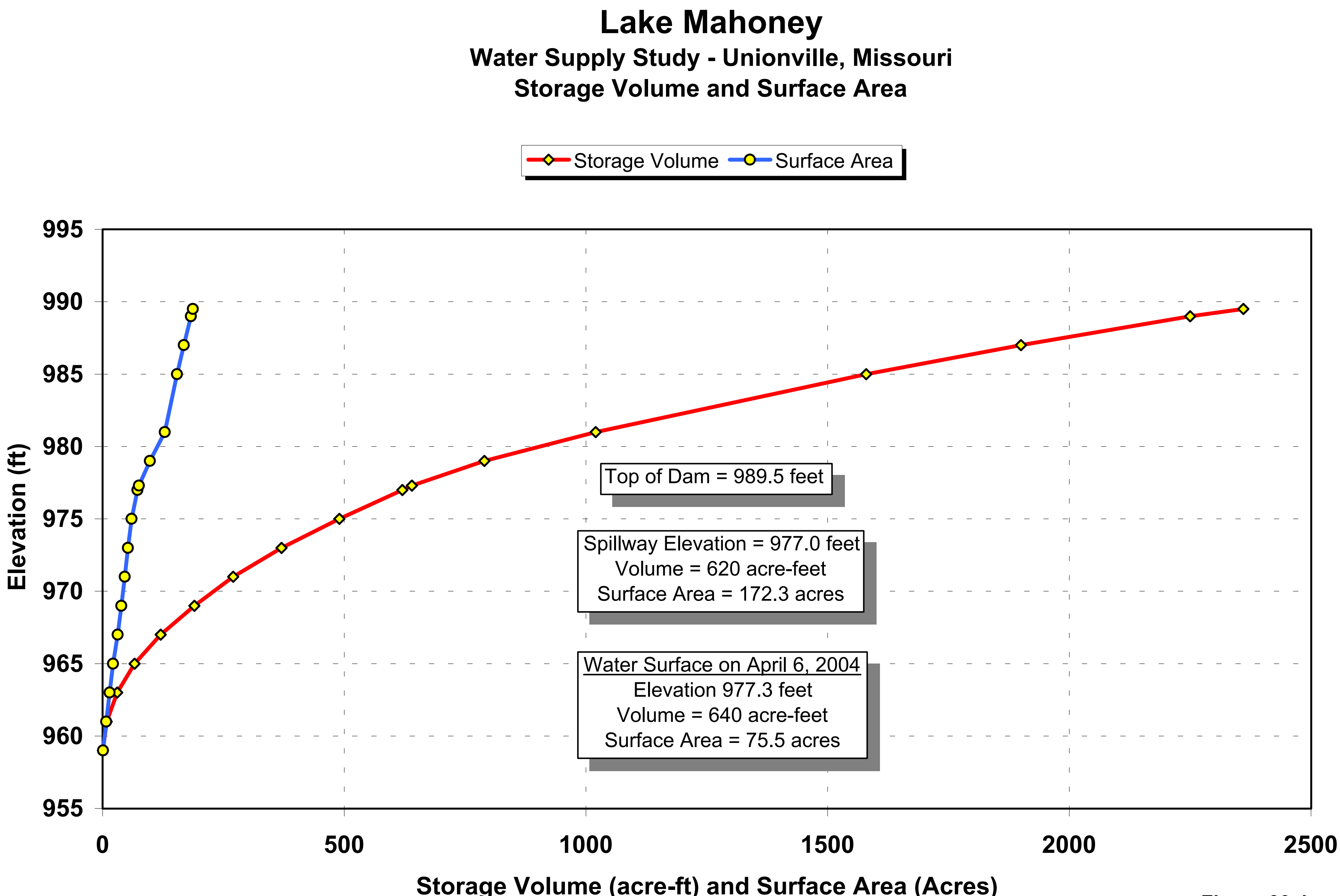

Lake Mahoney
Water Supply Study - Unionville, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Top of Dam = 989.5 feet
Spillway Elevation = 977.0 feet
Volume = 620 acre-feet
Surface Area = 172.3 acres
Water Surface on April 6, 2004
Elevation 977.3 feet
Volume = 640 acre-feet
Surface Area = 75.5 acres
Elevation (ft)
995
990
985
980
975
970
965
960
955
0
500
1000
1500
2000
2500
Storage Volume (acre-ft) and Surface Area (Acres)

Figure 39.4.a

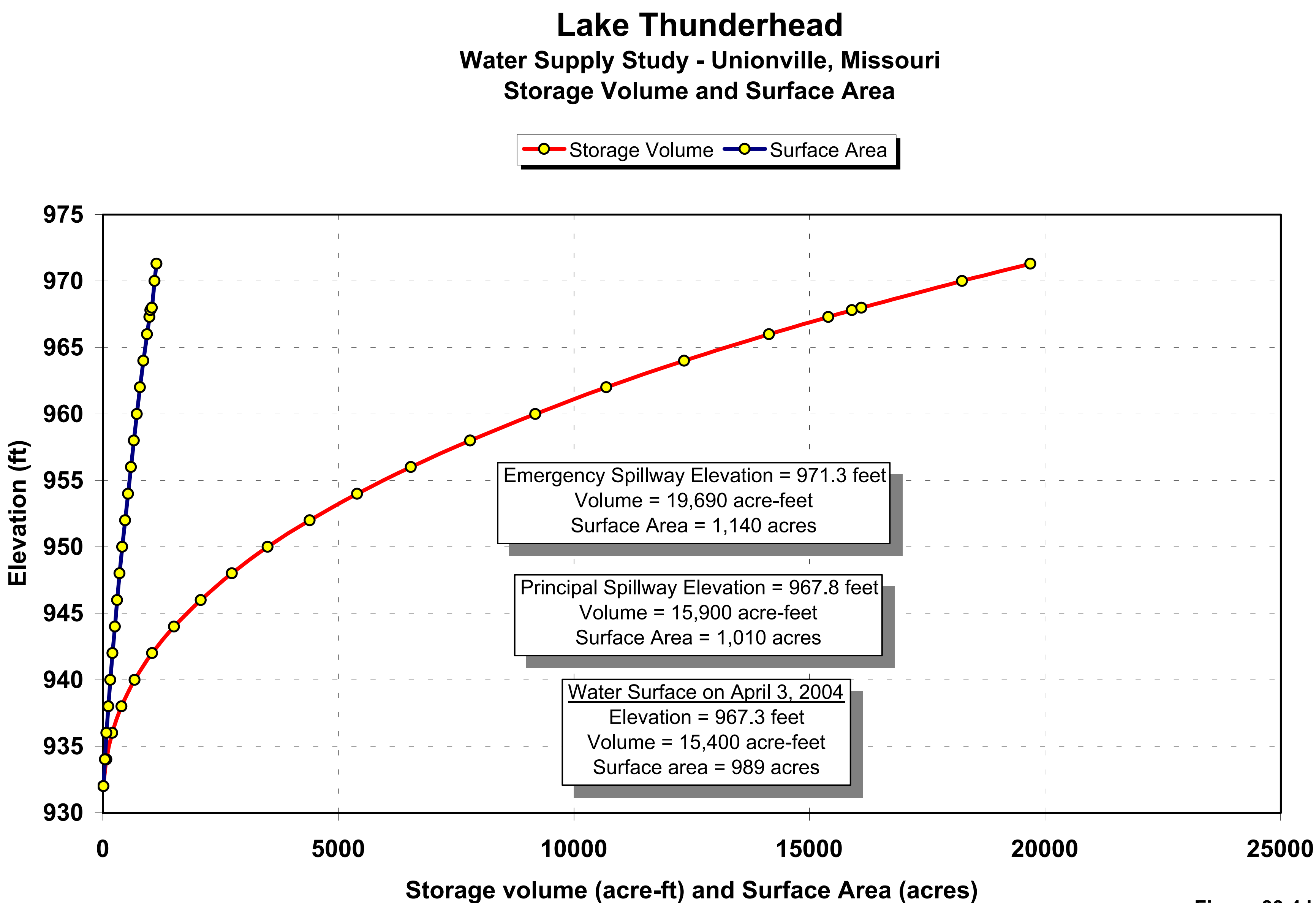

Lake Thunderhead
Water Supply Study - Unionville, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
975
970
965
960
955
950
945
940
935
930
Elevation (ft)
0
5000
10000
15000
20000
25000
Storage volume (acre-ft) and Surface Area (acres)
Emergency Spillway Elevation = 971.3 feet
Volume = 19,690 acre-feet
Surface Area = 1,140 acres
Principal Spillway Elevation = 967.8 feet
Volume = 15,900 acre-feet
Surface Area = 1,010 acres
Water Surface on April 3, 2004
Elevation = 967.3 feet
Volume = 15,400 acre-feet
Surface area = 989 acres

Figure 39.4.b

Vandalia Lake
Water Supply Study – Vandalia, Missouri
Drought Assessment Analysis

I. Overview

Vandalia is located in the extreme northeast corner of Audrain County. Vandalia Lake is located about 6.5 miles northeast of the City of Vandalia, in Pike County (figure 40.1). Vandalia Reservoir is the primary source of water for the City. The Vandalia Reservoir serves a population of approximately 2,863 with an estimated water demand of 0.25 million gallons per day according to the 2008 Census of Missouri Public Water Systems (maintained by the Public Drinking Water Branch, Missouri Department of Natural Resources).

The City of Vandalia draws water directly from the reservoir to the treatment facility, and the water supply to the city can be supplemented, if needed, with water from Mark Twain Reservoir as well as abandoned strip pits formerly used to mine clay for bricks. Historical demand on the reservoir in 2004 (figure 40.2) was reported to be 281,500 gallons per day. The trend for Vandalia water demand has increased about 1 percent per year from 1987 through 2004. This analysis evaluates Vandalia's Reservoir with no additional sources of water.

This water supply study was performed using the Reservoir Operation Study Computer Program (RESOP) developed by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). The RESOP model assesses the remaining water storage in a lake or reservoir by summing volumetric gains and losses on a monthly basis for a given year. Factors that are taken into account in the model include reservoir volume, drainage area, precipitation, seepage, evaporation, and others. Please refer to Appendix A for a more thorough description of the RESOP model program.

Two separate scenarios were modeled. The first scenario was for year 2000 demand of 0.259 million gallons per day. This analysis resulted in approximately 85 acre-feet of water remaining in the lake. Optimum analysis of the existing facility resulted in a demand of 0.33 million gallons per day. The second analysis considered raising the current spillway 3 feet in elevation. This analysis indicated the optimum demand would be increased to 0.38 million gallons per day. Figure 40.3 illustrates these relationships.

II. Drought Assessment Summary

The Vandalia Reservoir meets year 2000 demand but does not support a large additional demand during a drought such as the 1950's. The 2000 demand on the reservoir was approximately 25,900 gallons per day. When this demand is analyzed, only about 85 acre-feet of water remain in the reservoir. The estimated optimum yield from Vandalia Reservoir is 0.33 million gallons per day without additional water sources (figure 40.3).

III. RESOP Model Parameters

Terms in brackets (and bold text) refer to 'control words' for the RESOP program. Each term represents one or more values that are used to calculate the modeled water balance for the given reservoir or lake. The descriptions that follow describe the methodology and protocol for deriving these values. A detailed description of the variables addressed by each control word is provided in Appendix A.

[STO-AREA]

Volume and surface area data were derived from a bathymetric survey of Vandalia Lake conducted by the United States Geological Survey (USGS) under contract from the Missouri Department of Natural Resources on February 23 & 24, 2005. Surface area of the lake and associated storage volume capacity is illustrated in figure 40.4.

Vandalia Reservoir physical data

Vandalia Reservoir			
Elevation (feet)	Area (acres)	Volume (acre-ft)	
638	0	0	
640	0.1	0.1	
642	0.4	0.5	
644	0.6	1.6	
646	1.0	3.1	
648	2.7	6.4	
650	7.1	16.1	
652	10.1	33.6	
654	12.7	56.4	
656	15.7	84.8	
658	18.4	119	
660	21.3	159	
662	23.7	204	
664	26.1	253	
666	28.7	308	
666.3	29.1	317	Spillway and Water Surface elevation on February 23 & 24, 2005

[LIMITS]

Maximum Storage……………………………………………………………………….317 acre-feet
Minimum Storage……………………………………………………………………….20 acre-feet.
Drainage Basin Size……………………………………………………………………3666 acres.

Initial storage volume was equated to the reservoir volume at maximum capacity

[GENERAL]

The record period of drought occurred in the 1950's. The analysis period used in this model is January 1951 through December 1960.

[SEEPAGE]

Seepage from Vandalia Reservoir is approximately 2.0 inch per month when at or near full capacity and approaches 0.0 inches as the reservoir is emptied. The reservoir is bound by an earthen dam composed of compacted clay-rich materials - seepage through the dam is considered negligible.

[RAINFALL]

Rainfall data for the drought of record was obtained from Vandalia rain gauge and missing data was determined from Bowling Green records.

Average precipitation in Vandalia was 37.2 inches between 1950 and 2000. The most severe drought occurred between 1952 and 1957 with annual precipitation values in Vandalia of 25.04 inches, 27.08 inches, 28.51 inches, 32.45 inches, 29.07 inches and 40.49 inches, respectively.

[RUNOFF]

A monthly runoff volume in watershed inches was determined from data collected from the Youngs Creek stream gauge, located at Mexico approximately 15 miles west of Vandalia. The drainage area monitored by this stream gauge covers approximately 67.4 square miles. When this regional runoff value is inconsistent with precipitation values recorded for Vandalia, individual storm events were considered. Antecedent rainfall was determined for each storm event and adjustments to the Natural Resource Conservation Service's (NRCS) runoff curve number were made to estimate runoff from each storm event (see Appendix A for additional information).

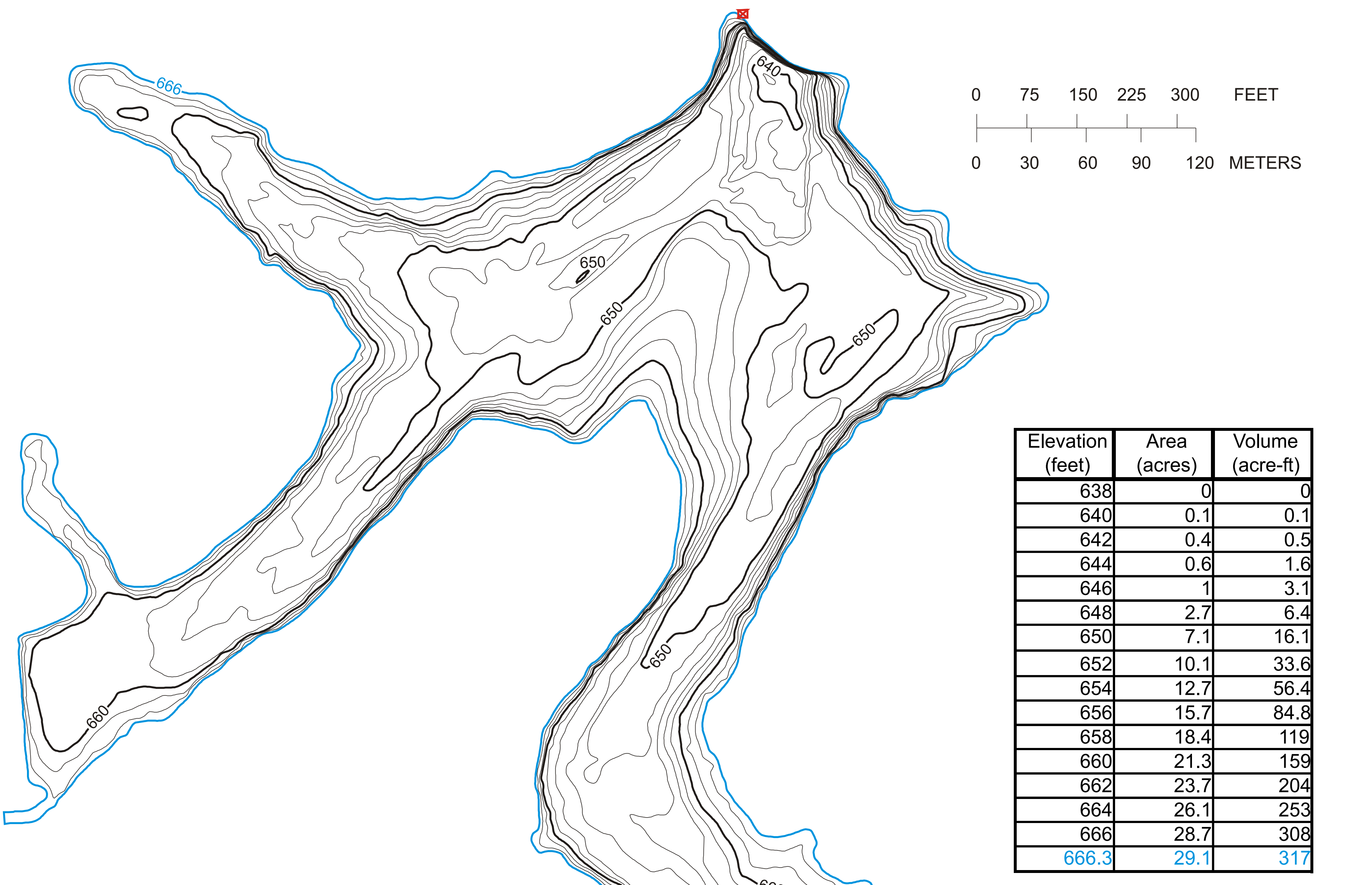
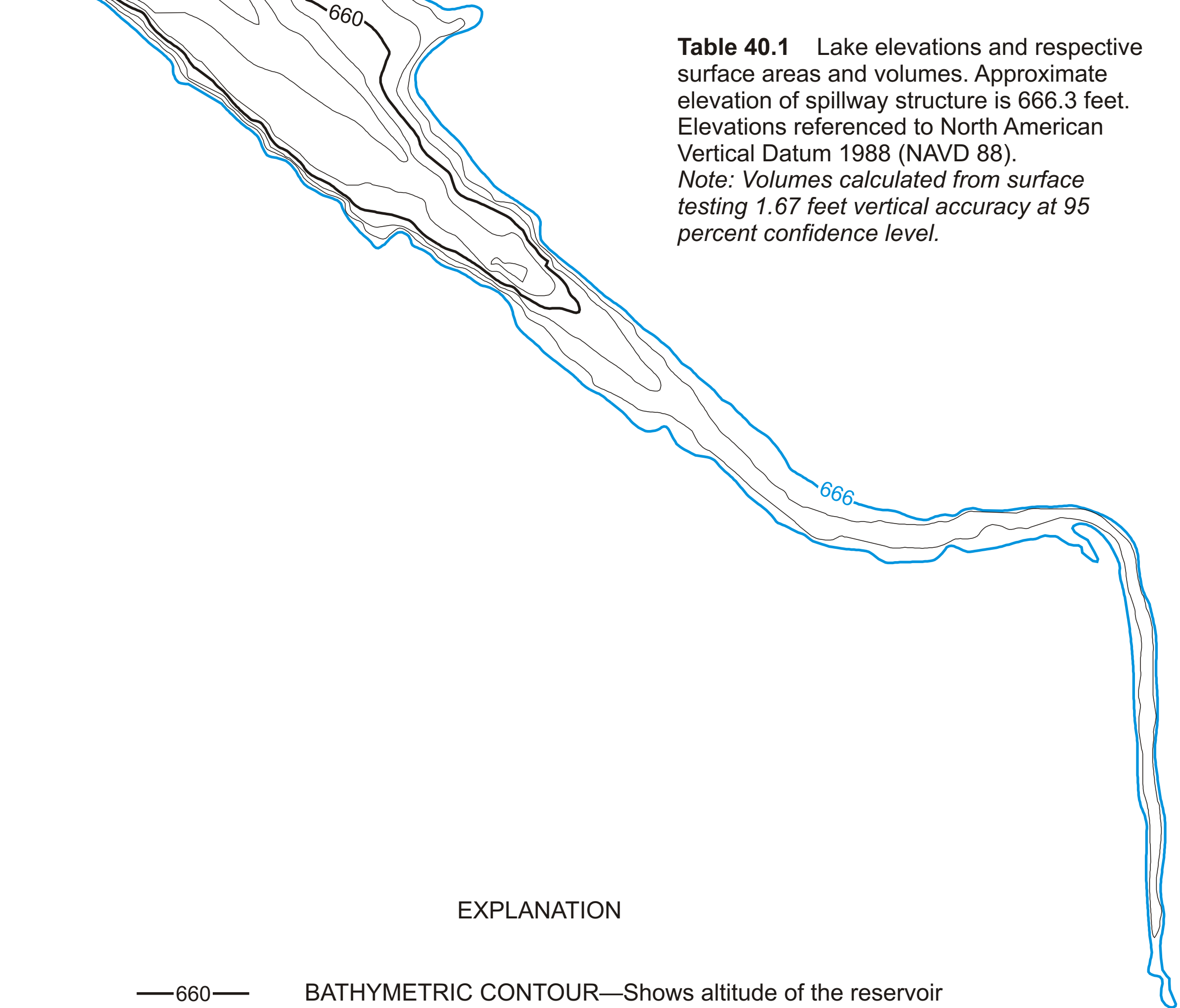
[EVAP.]

Pan evaporation rates from the Lakeside gauging station (near the Lake of the Ozarks) were used to estimate water loss from Vandalia Reservoir due to evaporation. This data was supplemented and compared with evaporation data from stations at New Franklin, Missouri or Washington University located in St. Louis, Missouri, depending on which station had the most recent data. An adjustment factor of 0.76 was applied to convert from pan evaporation to lake evaporation.

[DEMAND]

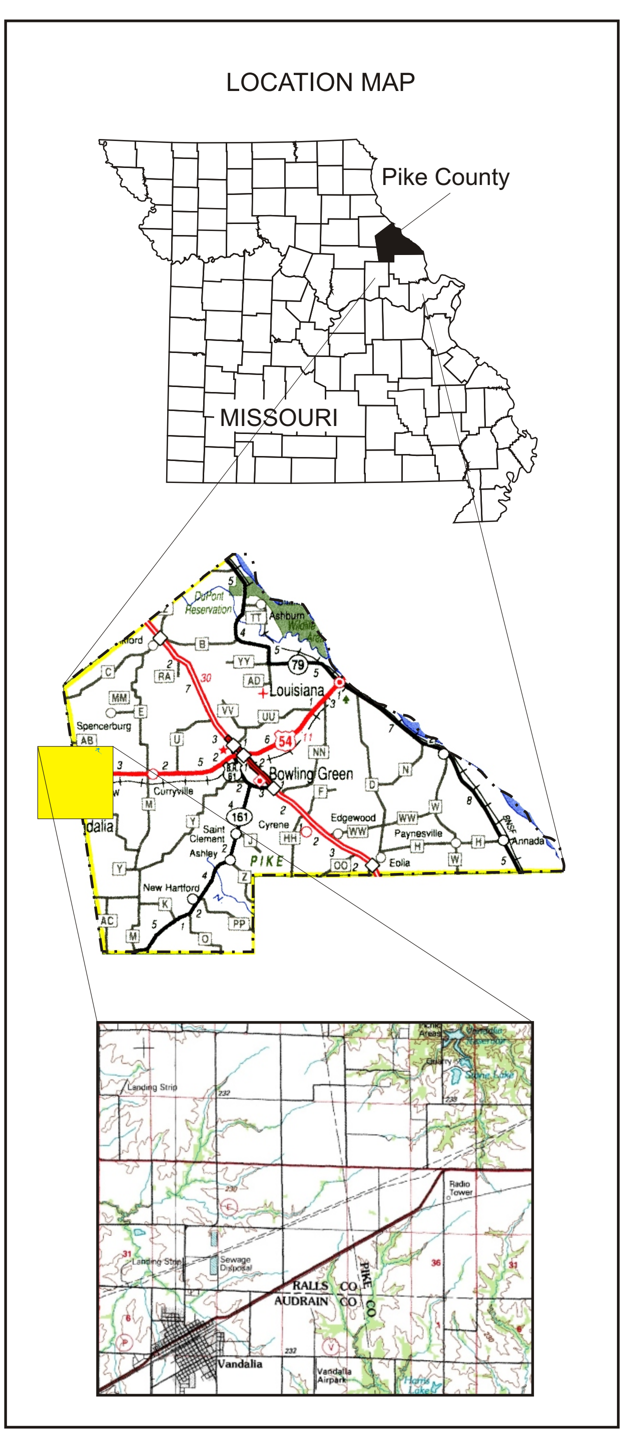
Water demand in 2000 was 0.259 million gallons per day, determined from information maintained in the Missouri Department of Natural Resources (Major Water Users Data Base). The total use in 2000 was 84,203,318 gallons.

VANDALIA RESERVOIR

Elevation (feet)	Area (acres)	Volume (acre-ft)
638	0	0
640	0.1	0.1
642	0.4	0.5
644	0.6	1.6
646	1	3.1
648	2.7	6.4
650	7.1	16.1
652	10.1	33.6
654	12.7	56.4
656	15.7	84.8
658	18.4	119
660	21.3	159
662	23.7	204
664	26.1	253
666	28.7	308
666.3	29.1	317

Table 40.1 Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 666.3 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).
Note: Volumes calculated from surface testing 1.67 feet vertical accuracy at 95 percent confidence level.



EXPLANATION

660 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Contours tested 1.73 feet vertical accuracy at 95 percent confidence level.

666 — WATER SURFACE—Shows approximate elevation of water surface (actual was 666.3 feet), February 23-24, 2005 (table 38).

U. S. GEOLOGICAL SURVEY REFERENCE MARKER—Southeast corner of 10 inch channel 28 feet northwest of intake house. Elevation 674.4 feet.

Figure 40.1

USGS
science for a changing world

Figure 40.1 Bathymetric map and table of areas/volumes of the Vandalia Reservoir near Vandalia, Missouri.

In cooperation with Missouri Department of Natural Resources

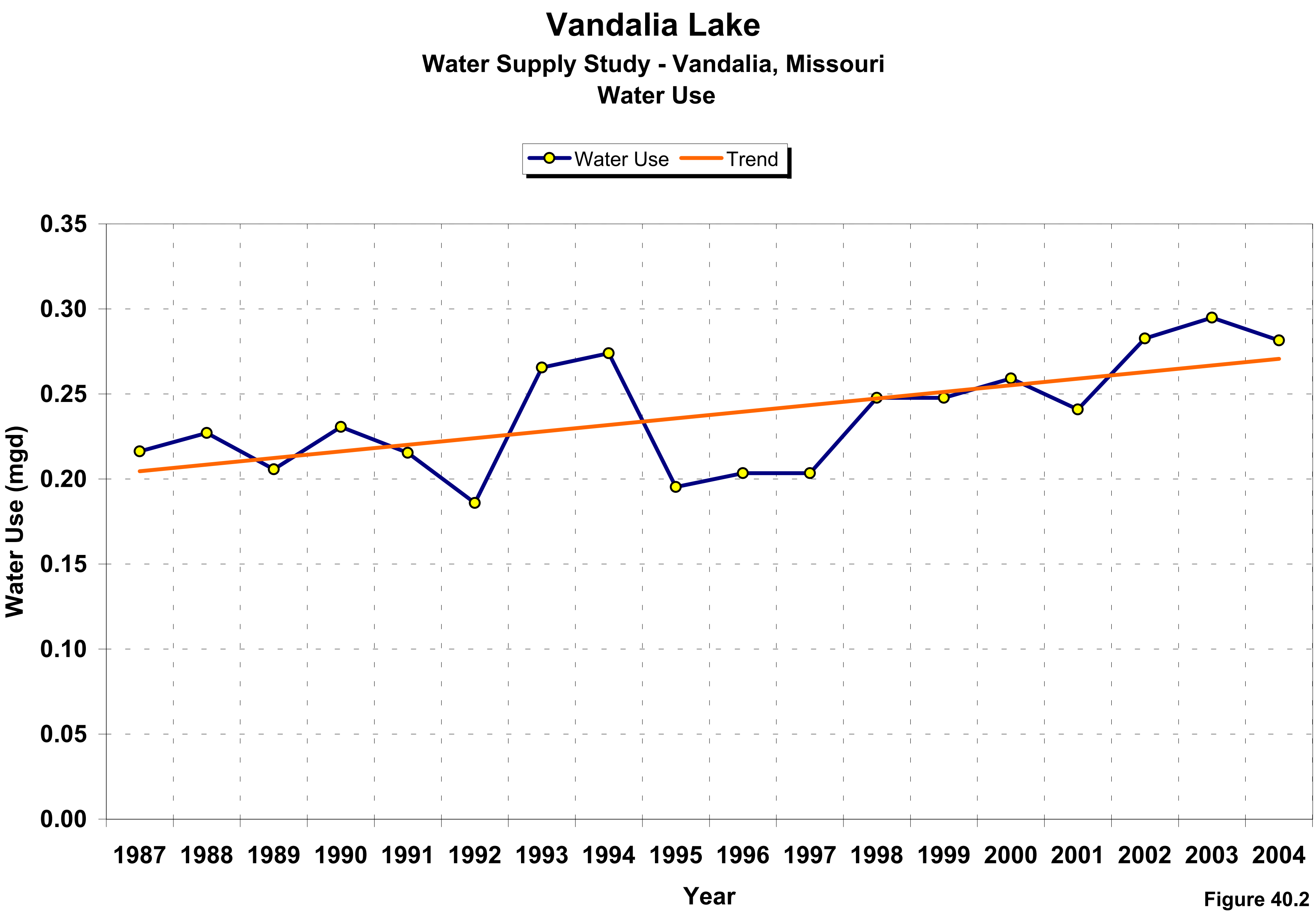

Vandalia Lake
Water Supply Study - Vandalia, Missouri
Water Use
Water Use
Trend
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Water Use (mgd)
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
Year

Figure 40.2

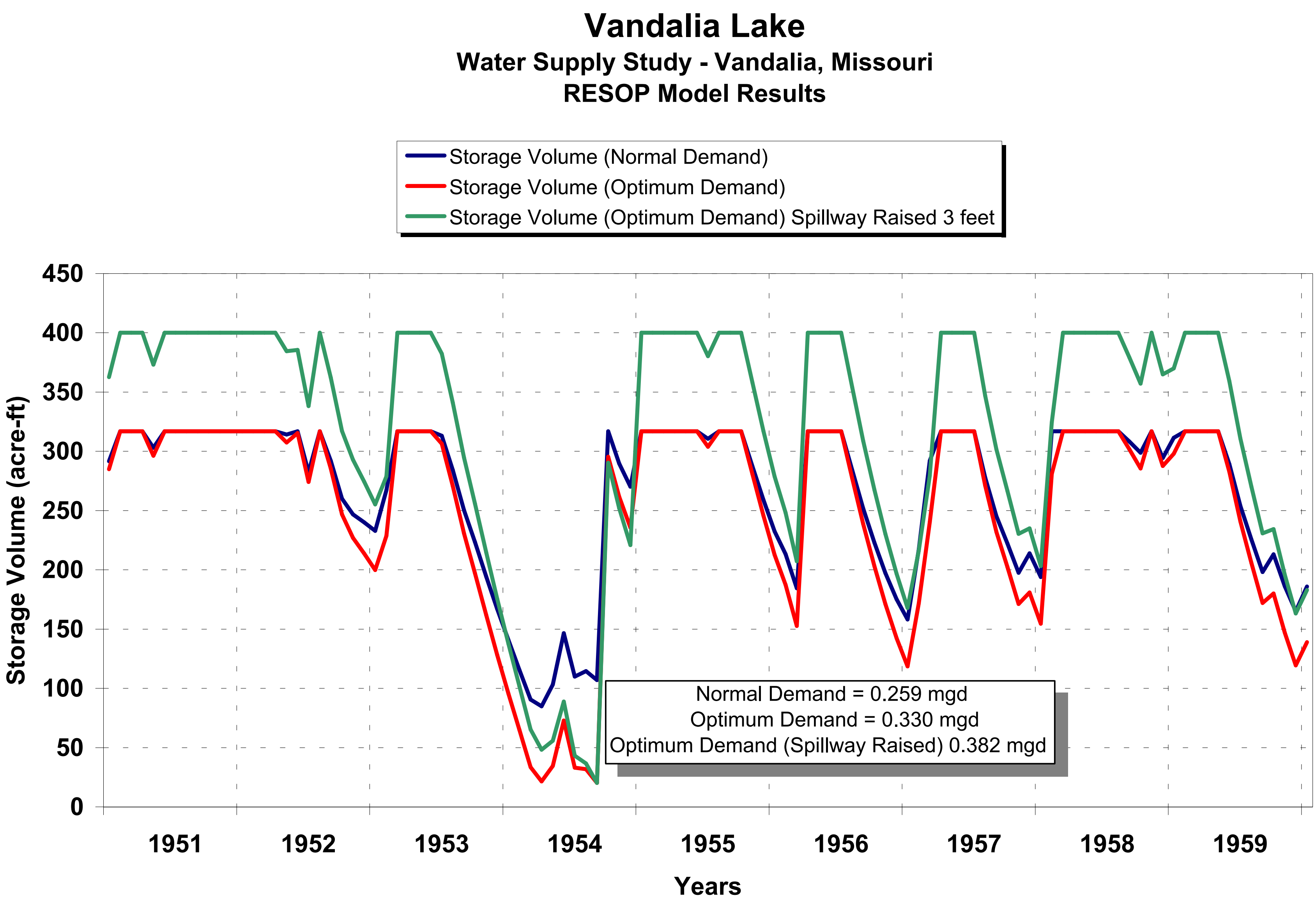

Vandalia Lake
Water Supply Study - Vandalia, Missouri
RESOP Model Results
Storage Volume (Normal Demand)
Storage Volume (Optimum Demand)
Storage Volume (Optimum Demand) Spillway Raised 3 feet
450
400
350
300
250
200
150
100
50
0
Storage Volume (acre-ft)
Normal Demand = 0.259 mgd
Optimum Demand = 0.330 mgd
Optimum Demand (Spillway Raised) 0.382 mgd
1951
1952
1953
1954
1955
1956
1957
1958
1959
Years

figure 40.3

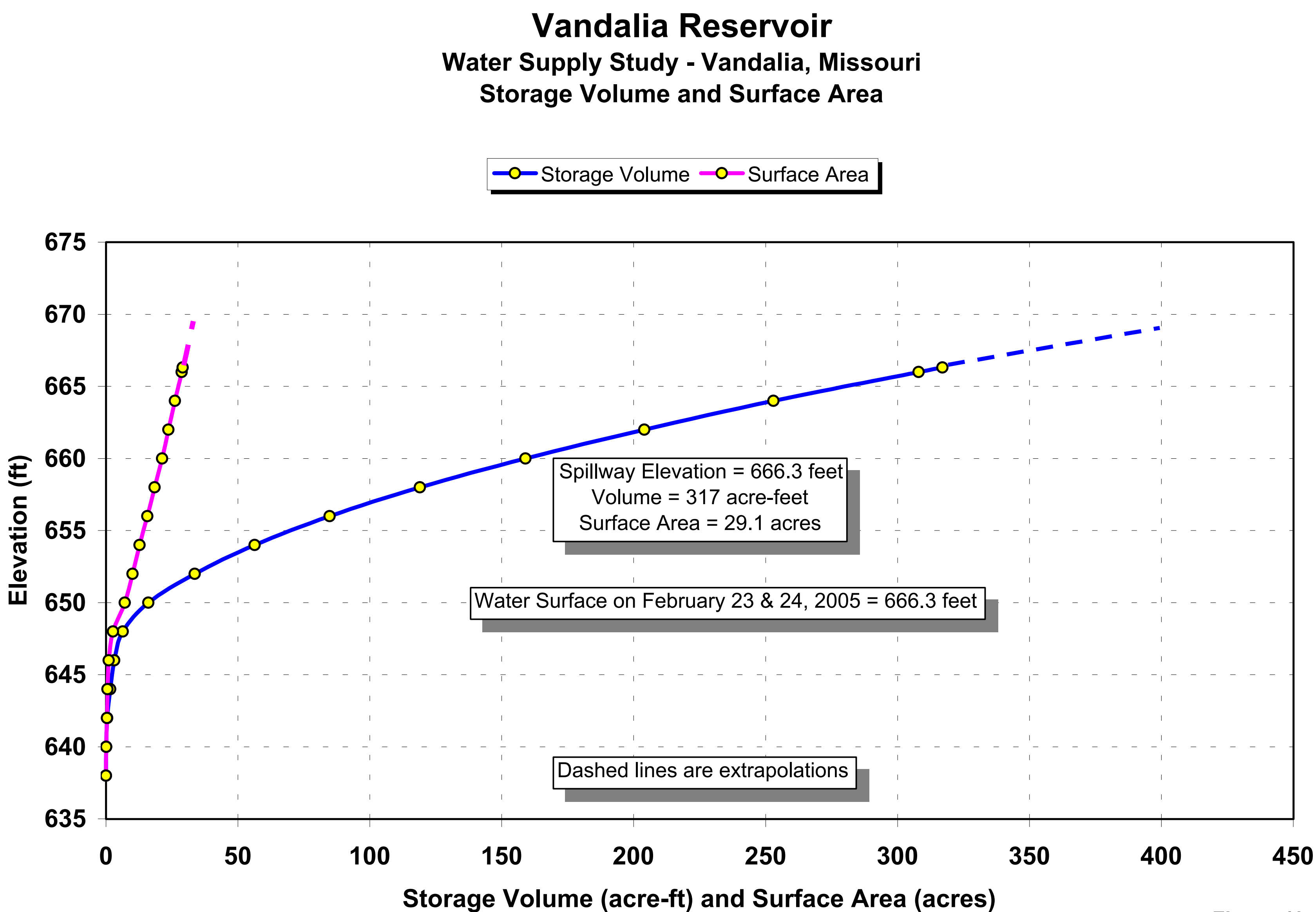

Vandalia Reservoir
Water Supply Study - Vandalia, Missouri
Storage Volume and Surface Area
Storage Volume
Surface Area
Elevation (ft)
675
670
665
660
655
650
645
640
635
0
50
100
150
200
250
300
350
400
450
Storage Volume (acre-ft) and Surface Area (acres)
Spillway Elevation = 666.3 feet
Volume = 317 acre-feet
Surface Area = 29.1 acres
Water Surface on February 23 & 24, 2005 = 666.3 feet
Dashed lines are extrapolations

Figure 40.4

Introduction to Stream and River Studies

Introduction

Four cities in Missouri that rely on stream flow for their water supply are Joplin, Perryville, Poplar Bluff and Trenton. Joplin depends on Shoal Creek, Perryville uses Saline Creek, Poplar Bluff uses Black River, and Trenton uses Thompson River. Stream flow must be adequate to meet withdrawal by the city. Flow must provide enough for downstream flow to meet in-stream-flow requirements. Monthly low flow duration analysis was made to determine the probability of stream flow depletion.

Stream Flow Analysis:

Many communities in Missouri utilize creeks and rivers to meet their municipal needs. Some streams do not have enough flow to meet immediate needs and off channel storage is required. Other streams, primarily in the Ozark Region where springs provide sufficient flow, have continuous discharges to meet consumptive use requirements.

Basic data for making stream flow frequency analysis was obtained from USGS published water supply papers. Mean daily discharges were used to analyze stream flow volumes and frequencies. Gauges having long term records were used to evaluate extended periods of drought. Gauge data is published as mean daily discharge, in cubic feet per second. Analysis was made on a monthly basis. A comparison of a shorter drought of seven days is also presented. To meet in-stream flow requirements, the 7-day duration, 10-year frequency mean discharge was determined. Only when flows exceeded the in-stream flow requirements were withdrawals allowed for domestic uses. All frequency analysis was made using the “Log-Pearson Type III Probability Method”. This procedure is described on the Water Resource Council Bulletin 17B.

To establish base flow in the streams, USGS computer program “HYSEP” was used. The program separates the base flow hydrograph from the total discharge hydrograph.

The monthly frequency analysis was also compared to historical stream flows of the 1950s drought of record. This identified the months of critical stream flow that could be expected to occur during an extreme drought. All analysis results are presented in a series of charts displayed for each month of the year.

Glossary

Definition of terms

cfs – Discharge in cubic feet per second.
MG -- million gallon
mgd – million gallon per day
gpm – gallon per minute
USGS – United States Geological Survey
Acre feet – Volume of water covering one acre, one foot deep.
USGS Bulletin 17B - The USGS Guideline for Determining Flood Flow Frequency. It describes the data and procedures for computing flood flow frequency curves where systematic stream gauging records are of sufficient length to warrant statistical analysis.

Log-Pearson Type III Probability Method. The annual values are fit to a Log-Pearson Type III probability distribution. If minimum values are used, the result is non-exceedance probabilities. If the maximum values are used the result is exceedance probabilities.

The observations are fit to the Log-Pearson Type III distribution using the following equation:

$$\log Q = X + KS$$

Where Q is the expected discharge, X is the mean logarithm of the observed values, S is the standard deviation of logarithms of the observed values and K is a factor that is a function of the skew coefficient of the observed values and the selected non-exceedance probability.

7Q10 – The mean 7-day duration, 10-year frequency low flow is the minimum flow needed for in-stream flow requirements.

HYSEP - A USGS computer program that separates the base flow hydrograph from the total hydrograph.

Runoff in Watershed (inches) – The volume of runoff from the entire drainage area of the basin, in inches.

WHPA Report – Report on problems of the Ozark aquifer and associated problems with supply and demand. Titled “Source of Supply Investigation for Southwestern Missouri.” Prepared by Wittman and Associates.

JOPLIN, MISSOURI
Water supply Study
Shoal Creek

Overview

This analysis was made to assess the availability of Joplin's water supply. Joplin obtains their water supplies from a combination of Shoal Creek and wells. Shoal Creek is the major contributor. There are 8 to 14 million gallons per day (mgd) pumped from Shoal Creek, which is fed by numerous springs throughout its drainage area. Joplin has no facility for storing raw water off channel. Wells contribute 1.2 to 1.9 mgd. The first part of this report examines availability of stream flow and withdrawals from Shoal Creek. The second part of the report addresses contributions by wells. The WHPA report assesses the problems associated with excessive use of ground water in the region.

Shoal Creek Stream gauge above Joplin is located 1400 feet downstream of state highway 86. The drainage area above the stream gauge is 427 square miles. Missouri-American Water Company provides the water supply. The pump intake is located ¾ mile downstream of highway I-44, which is about 4.5 miles downstream of the gauge (NE ¼, sec 28, T27N, and R33W). Figure 45.1 shows that the long-term trend (1995 through 2002) daily water usage has increased from a total of approximately 10.6 mgd in 1995 to 12.2 mgd in 2002, resulting in an average daily increase in use of 15 percent.

Stream flow data was obtained from USGS water supply papers. Mean daily discharges were used to analyze stream flow volumes and frequencies. Continuous records have been maintained from 1941 through 2002. Neosho also uses water from Shoal Creek. Their intake is about 25 miles upstream of the stream gauge above Joplin. Neosho takes an average of 1.6 mgd from Shoal Creek. For this report, all statistical determinations were made using the Log Pearson type III method as described in Water Resource Council bulletin 17B.

Drought Assessment:

Joplin has no facility for storing raw water off channel.

Annual precipitation amounts for most of Missouri have been increasing. This is shown in the state water plan. The study was recently made for the state by Steve Hue (Former state climatologist at University of Missouri) to update climate data. Annual rainfall has increased several inches in the last 50 years. Figure 45.2 illustrates the annual precipitation and trend for Joplin. This station shows the trend in annual precipitation increasing from 35 inches to 50 inches, an increase of 42 percent for the years 1950 through 2000. Figures 45.3.a and 45.3.b show the effect of increased annual rainfall on runoff. The trend indicates an increase in total annual runoff from 12.5 inches to 19 inches or approximately 52 percent from 1950 to year 2000. These two figures are displayed in terms of watershed inches and also cubic feet per second.

Base flow separation was made using the USGS computer program, HYSEP. HYSEP separates the base flow hydrograph from the total hydrograph. This analysis was made to estimate sustained flow, in order to establish availability of continuous stream flow. Figure 45.4.a is the base flow index and is the ratio of base flow to total stream flow. This chart shows the yearly fluctuation in base flow indexes and indicates the trend. The trend has increased from 68 percent of total runoff in 1942 to 76 percent in 2000, about an 8 percent increase. Figure 45.4.b displays volume of base flow in terms of watershed inches of runoff. Figure 45.4.c shows the base flow in terms of mean cfs. The trend shows the mean base flow to be about 300 cfs in 1942 with a low of 250 cfs in 1964 and increasing to a 450 cfs in year 2000.

Mean seven-day annual low flows for 1928 through 1999 were calculated and are shown in figure 45.5. The lowest 7-day discharge occurred in 1954 with a mean value of 15.9 cfs for the year.

The drought of record was in the 1950's. Non-exceedance probabilities for the 1%, 2% and 4% chance flows in figure 45.6 are compared to actual stream flow records in figures 45.7.a through 45.7.d for the period 1953 through 1956**.** Figure 45.7.a compares 1953 mean monthly flow to monthly probability, Figure 45.7.b to 1954, and Figure 45.7c to 1955 and Figure 45.7.d to 1956. Monthly probabilities are based on years 1950 through 2000.

To assure that water quality standards are met most of the time, the mixing zone flow is based on the seven-day average low flow that has a recurrence interval of once in 10 years (7Q10). To determine the rate of flow needed to meet in-stream flow needs, the 7Q10 flow was determined using the period of record, 1950 through 2000. **Figure 45.8** shows the results of the frequency analysis to be 43 cfs. For purposes of diverting water from the creek, discharge needed to exceed 43 cfs.

Additional comparisons for the 1950's drought were made at the Joplin intake point using the mean 7-day low flow for examination of a shorter duration. These comparisons are shown in figures 45.9.a, 45.9.b, 45.9.c and 45.9.d. These figures indicate short-term 7-day duration mean low flows during the drought of record, by months, for years 1953, 1954, 1955 and 1956. For 1953, September and October, flows nearly equaled 43 and 41. In 1954, the driest year on record, June through September mean flows were 40, 27, 18 and 16 cfs. In 1955 and 1956 all mean flows would allow diversion from Shoal Creek. In October 1956 mean flow was 39 cfs, which is dangerously low for diversion.

In addition comparisons for the 1950's drought were made at the Joplin intake point using the mean 7-day low flow. Figure 45.10.a shows low flow not expected to be less than, or non-excedence probability for the 1% chance of low flow compared to the flow needed to meet demand. This indicates that eight months out of the year stream flow is adequate for diversion and allowing the 7Q10 frequency discharge to provide for water quality standards to be met. Figures 45.10.b.is the two- percent chance of occurrence and indicates only 2 months, November and December, are close to the minimum but probably would allow pumping. Figure 45.10.c shows that the 4% chance of occurring is able to provide enough flow so that there is only a very small deficit in November. Figures 45.10.d and 45.10.e display the deficits in bar charts, one showing the deficit in acre-feet and the other in terms of cfs.

The following shows the average daily and yearly water withdrawal from Shoal Creek, at Joplin, for the period 1995 through 2002. Usage has been fairly constant. Daily data for this time period was submitted by the Missouri-American Water Company and can be observed in file "Shoal Creek pumpage.xls".

Year	Daily Withdrawal	Yearly Withdrawal
1995	10.467 mgd	3,453.290 million gallon
1996	10.916 mgd	3,995.330 million gallon
1997	10.650 mgd	3,878.840 million gallon
1998	12.068 mgd	4,406.896 million gallon
1999	11.207 mgd	4,090.036 million gallon
2000	10.990 mgd	4,024.792 million gallon
2001	10.608 mgd	3,876.281 million gallon
2002	10.825 mgd	3,957.166 million gallon

Neosho water use from Shoal Creek.

Year	Daily Withdrawal	Yearly Withdrawal
1997	1.220 MGD	445.335 million gallon
1998	1.233 MGD	499.965 million gallon
1999	1.617 MGD	590.220 million gallon
2000	1.916 MGD	699.344 million gallon
2001	1.943 MGD	709.376 million gallon

Wells

Deep wells in this region are in the Ozark aquifer. Because of the increasing demand in the area, it is becoming harder for this aquifer to meet the needs. A ground water study has been made for the region by WHPA, titled *Community Data Report, Source of Supply Investigation for Southwestern Missouri.* It is available on the Internet. The web site is www.wittmanhydro.com. This report describes wells in the region and associated problems.

Following is information on wells and withdrawal rates that are reported for each city. These are:

- Carl Junction, Mo. has seven wells with six currently in use, and plan to drill two more.
- In 2000 they pumped 201.5 million gallon, an increase of 37 percent since 1987.
- Carterville, Mo. has one well and yielded 74 million-gallon in 2001, an increase of 16 percent since 1994.
- Carthage, Mo. has 17 wells of which 16 are currently being used. In year 2000, there were 1,126 million gallons pumped, an increase of 39 percent since 1987.
- Duenweg, Mo. has two wells in use pumping 41 million gallons per year. The demand has increased 18 percent since 1987.
- Jasper Rural Water District Number One has one well and pumped 60 million-gallon per year in 2001. Two additional wells are planned.
- Neosho, Mo. has five wells that pump 429 million gallons per year in year 2000, an increase of 28 percent since 1997, when they began pumping from wells.
- Oronogo, Mo. has two wells that pump a combined amount or 45 million-gallon, an increase of 81 percent from 1990 to 2000.
- Pittsburg Ks. has four wells and pump about 1,000 million gallons annually, with very little change in demand.
- Webb City Mo. has 13 wells with only seven in use. They are pumping 400 million gallons per year.

Not found in the summary report is the Joplin well usage. Joplin has six wells to supplement their water supply from Shoal Creek. The combined annual pumping rates for 1996 through 2002 are listed below. Monthly values are available and may be observed in file “well_pumpage.xls”.

Year	Yearly Withdrawal
1996	143.366 million gallons
1997	176.914 million gallons
1998	140.504 million gallons
1999	201.697 million gallons
2000	342.766 million gallons
2001	244.248 million gallons
2002	431.388 million gallons

Conclusion:

Because of the many springs in the drainage area of Shoal Creek, the mean monthly minimum flows were never depleted. The minimum low flow for the period of record was 16 cfs in August and September of 1954. This low flow stayed below 20 cfs for 14 days in succession. For the period 1979 through 2000, the minimum mean daily low flow was 30 cfs in 1981 and was below 55 cfs for two days. These two times are the only times flow was below the 7Q10 low flow for the period of record.

Joplin's water demand has increased during the period 1995 through 2002 at a rate of 0.20 mgd or 1.9 percent per year.

The 7Q10 discharge of 43 cfs exceeded the 1% chance or 1 year in 100 years, low flows for seven months, mean monthly Shoal Creek discharges were between 2 and 5 cfs less. These months are January, February, March, August, October, November and December. For the 2% chance or 1 year in 50 years, all monthly mean flows exceeded the 7Q10 flows.

During the 1950's there were no months that flow in Shoal Creek would not allow pumping for at least some of the month. However there would be shorter periods of time flows would be too low for pumping. This is indicated by the 7-day low mean discharge values for 1953, 1954, 1955 and 1956. Each year had mean 7-day duration flows below pumping range.

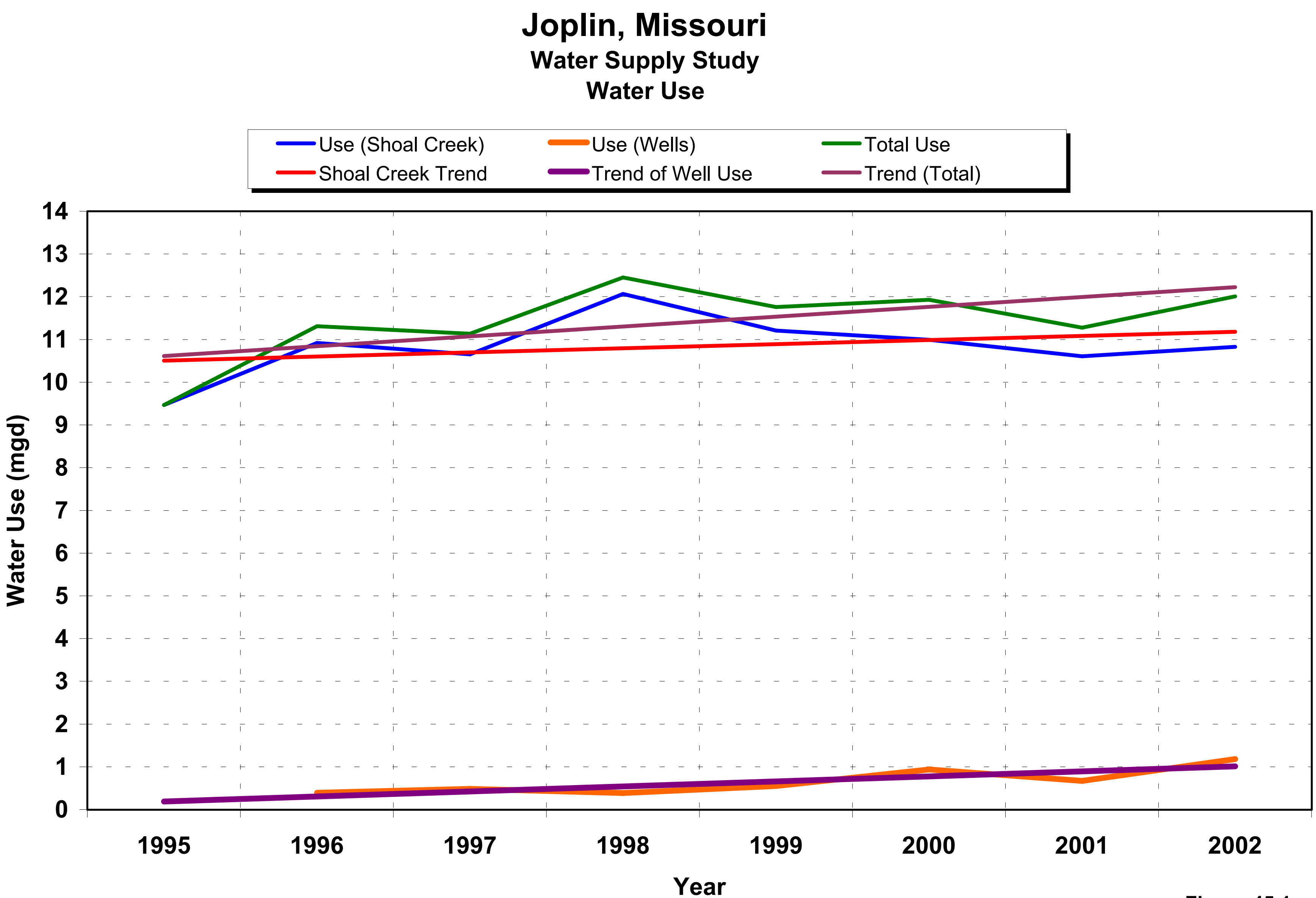

Joplin, Missouri
Water Supply Study
Water Use
Use (Shoal Creek)
Use (Wells)
Total Use
Shoal Creek Trend
Trend of Well Use
Trend (Total)
Water Use (mgd)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
1995
1996
1997
1998
1999
2000
2001
2002
Year

Figure 45.1

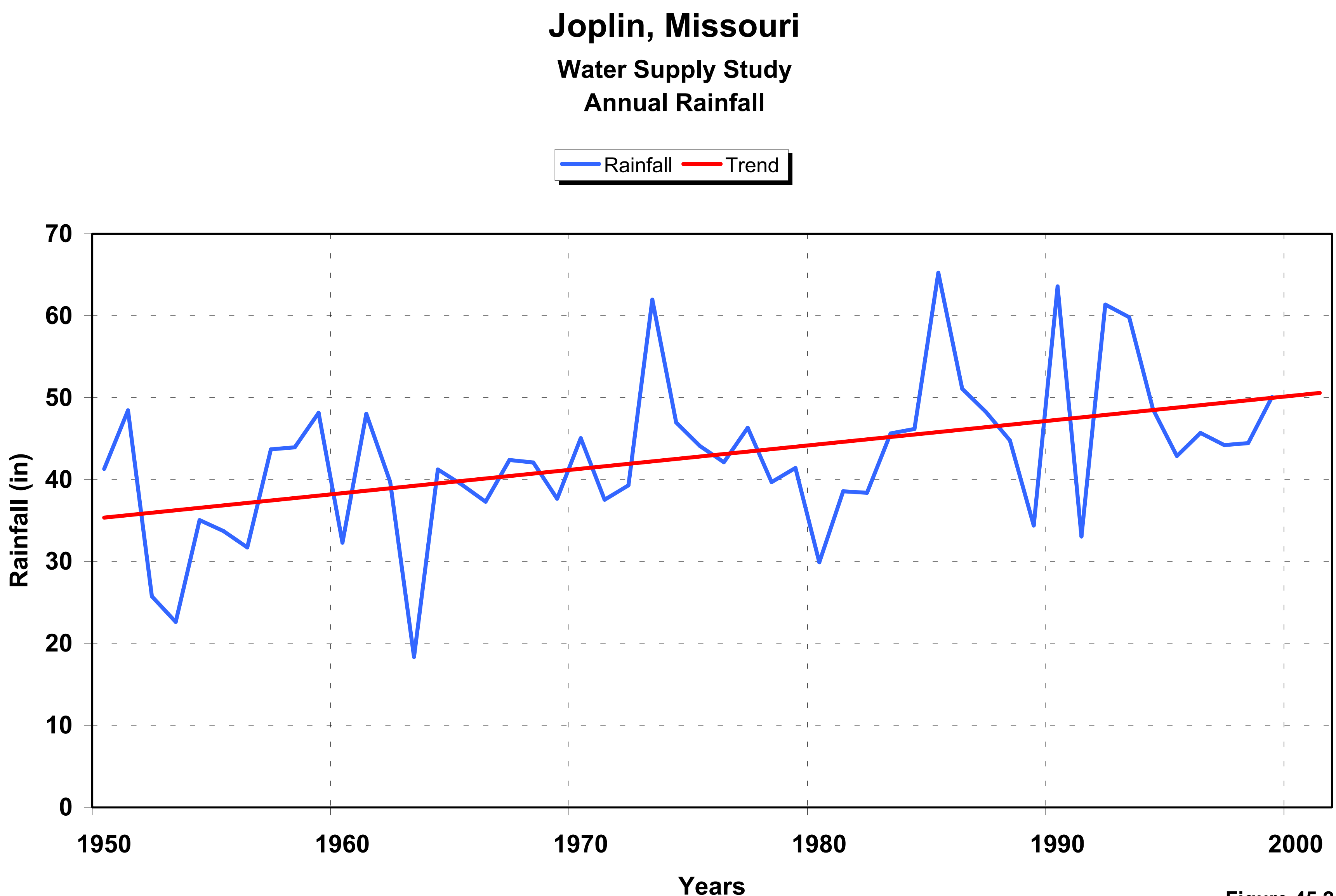

Joplin, Missouri
Water Supply Study
Annual Rainfall
Rainfall
Trend
70
60
50
40
30
20
10
0
Rainfall (in)
1950
1960
1970
1980
1990
2000
Years

Figure 45.2

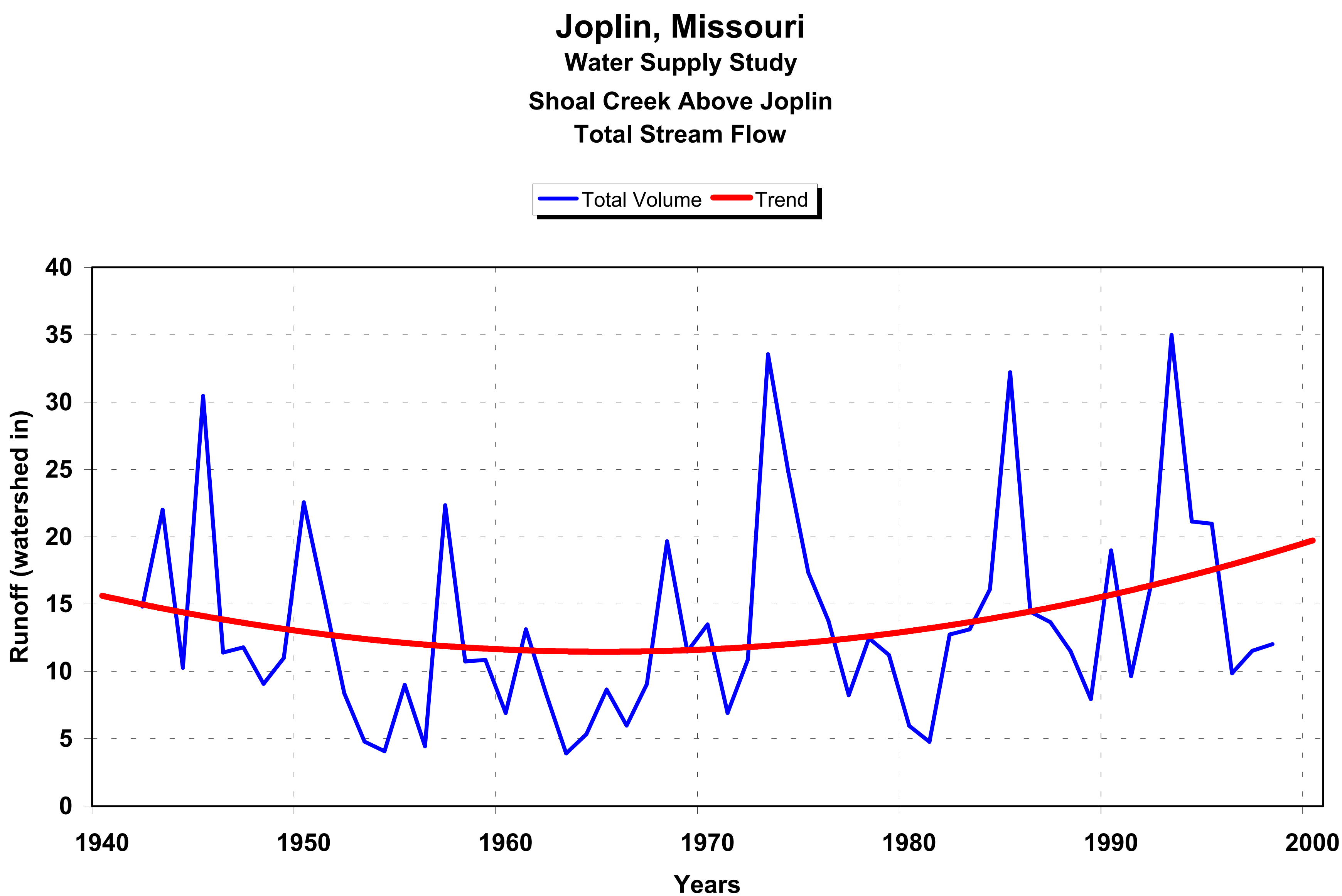

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Total Stream Flow
Total Volume
Trend
Runoff (watershed in)
0
5
10
15
20
25
30
35
40
1940
1950
1960
1970
1980
1990
2000
Years

Figure 45.3.a

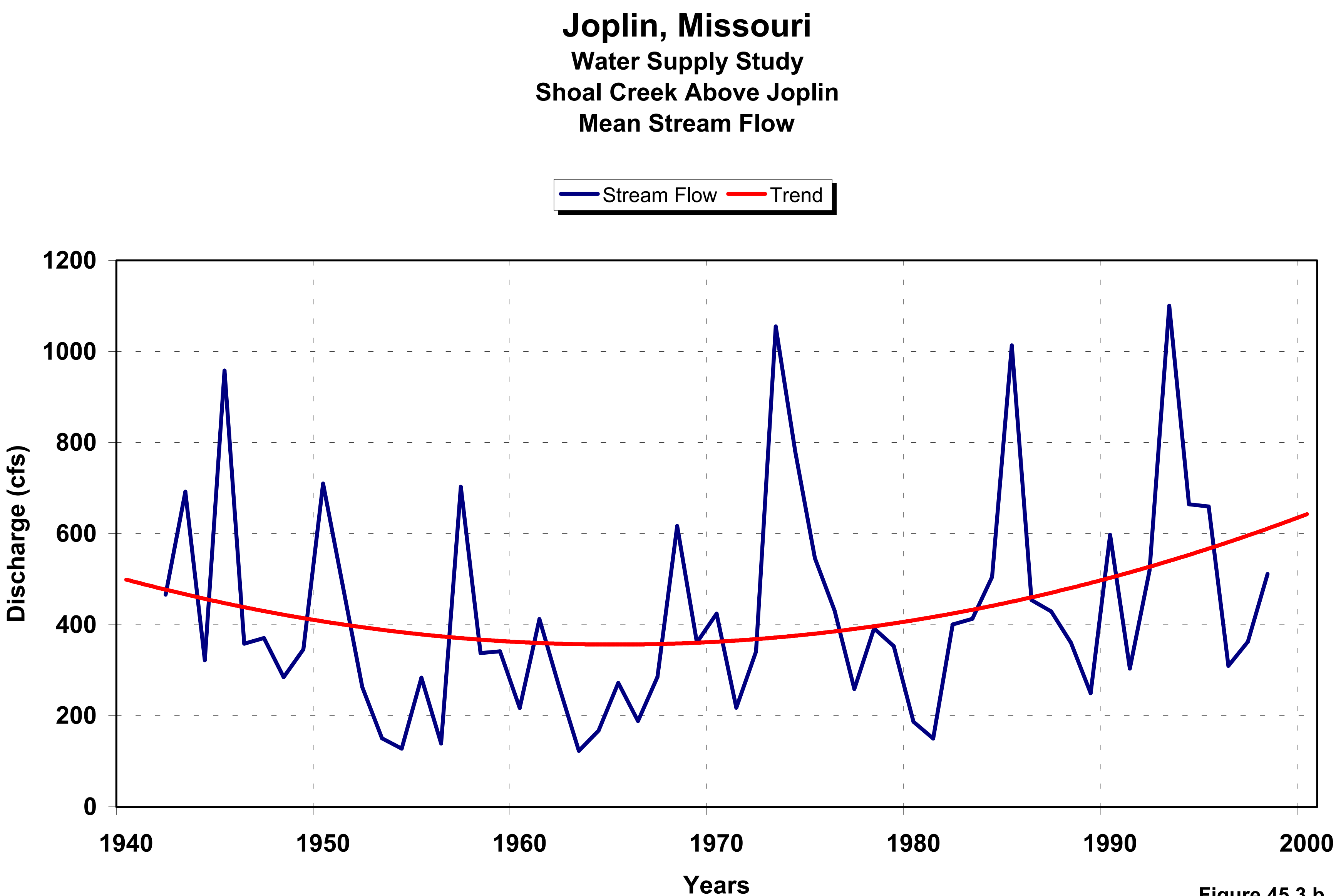

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Mean Stream Flow
Stream Flow
Trend
1200
1000
800
600
400
200
0
Discharge (cfs)
1940
1950
1960
1970
1980
1990
2000
Years

Figure 45.3.b

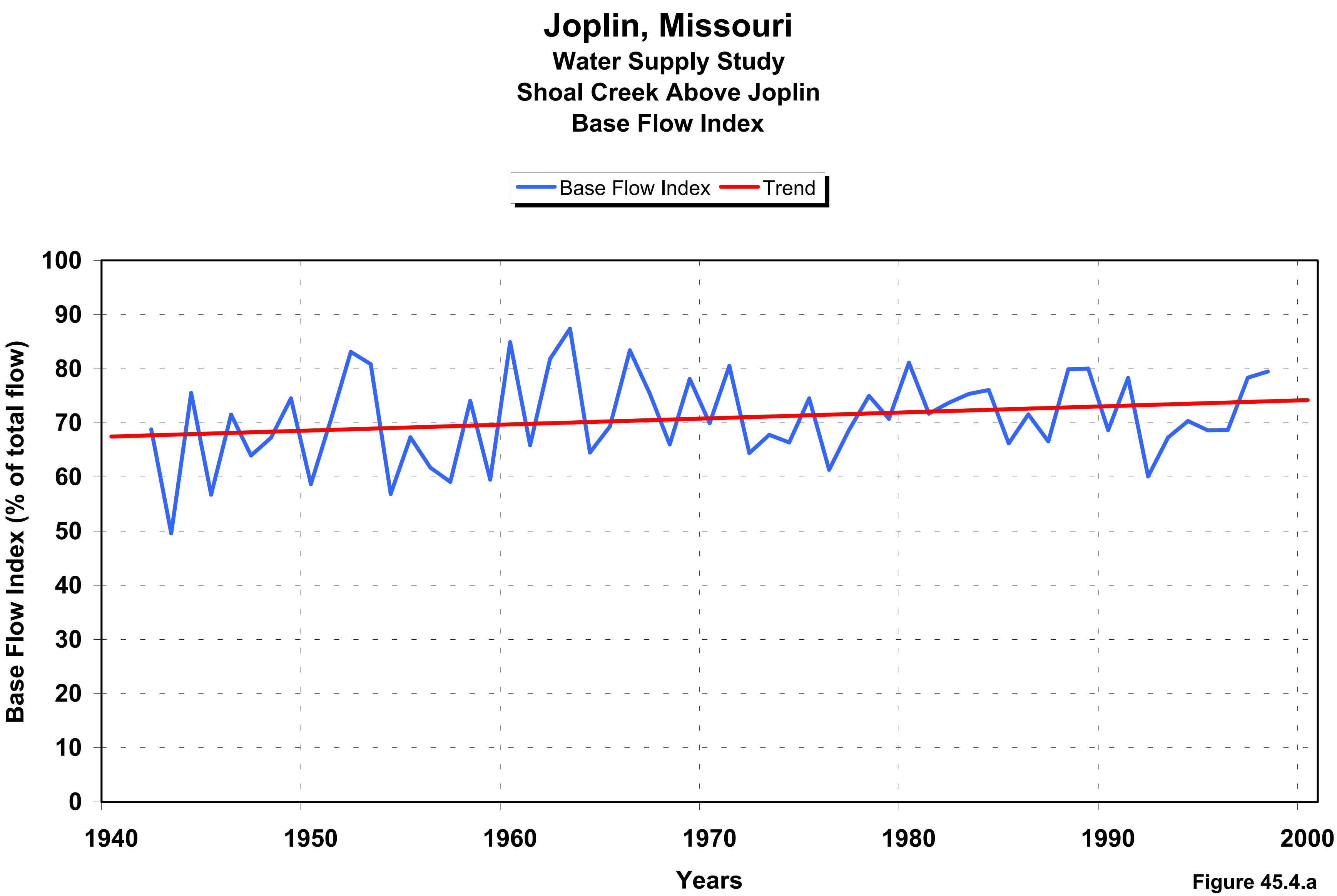

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Base Flow Index
Base Flow Index
Trend
Base Flow Index (% of total flow)
100
90
80
70
60
50
40
30
20
10
0
1940
1950
1960
1970
1980
1990
2000
Years

Figure 45.4.a

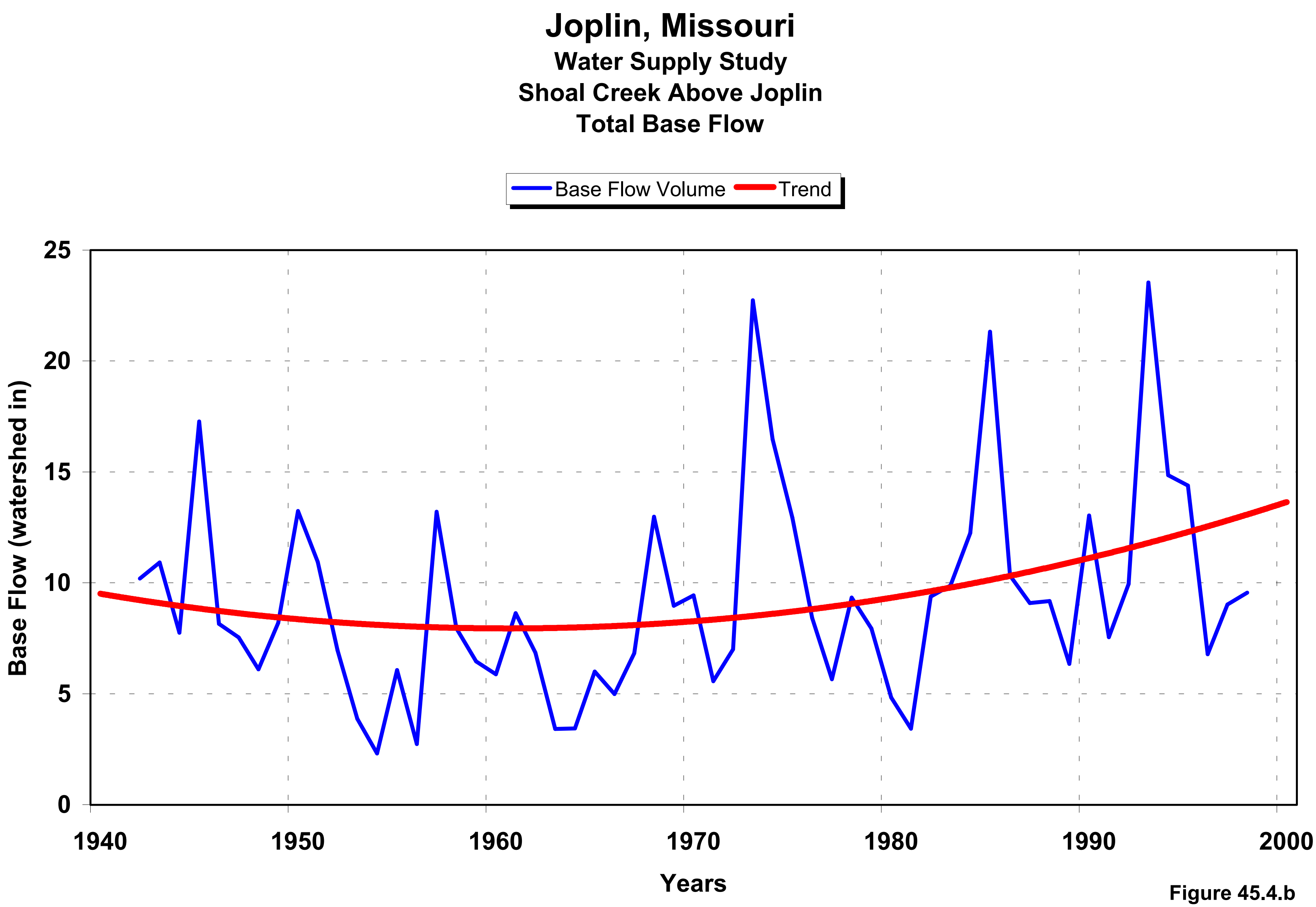

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Total Base Flow
Base Flow Volume
Trend
Base Flow (watershed in)
0
5
10
15
20
25
1940
1950
1960
1970
1980
1990
2000
Years

Figure 45.4.b

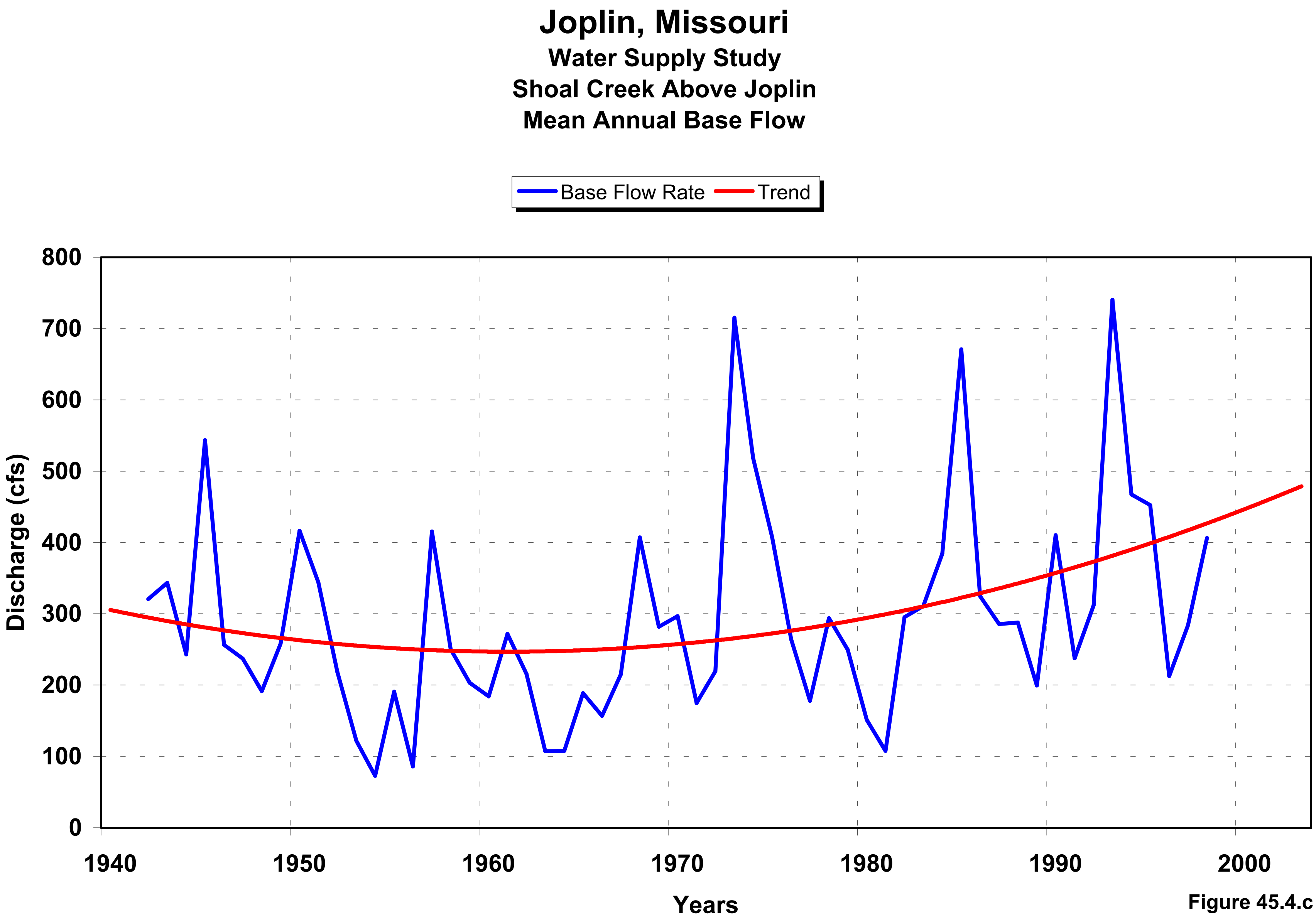

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Mean Annual Base Flow
Base Flow Rate
Trend
800
700
600
500
400
300
200
100
0
Discharge (cfs)
1940
1950
1960
1970
1980
1990
2000
Years

Figure 45.4.c

SHOAL CREEK

Water Supply Study
Shoal Creek Above Joplin
Mean 7-Day Low Flow

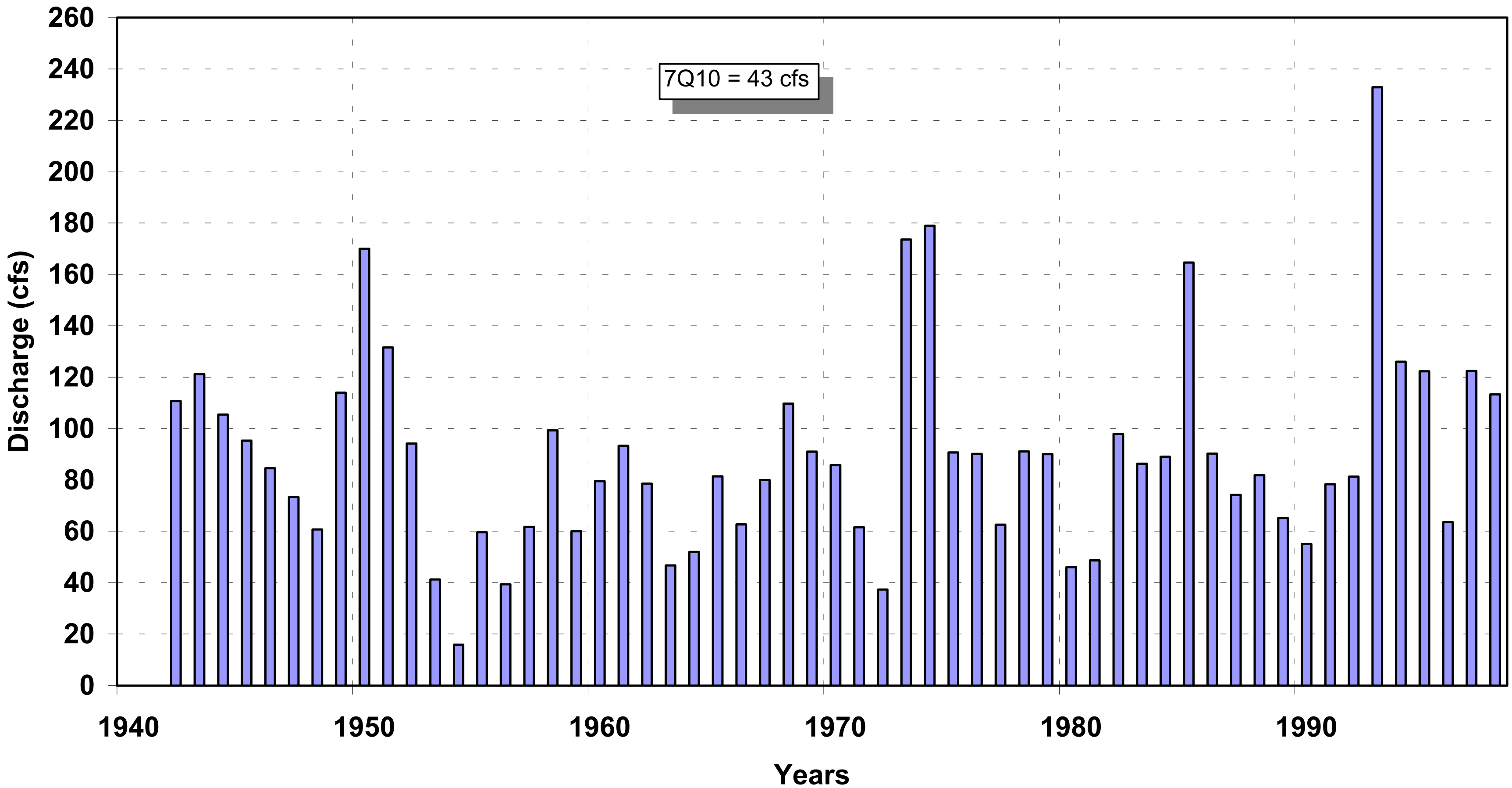


Figure 45.5

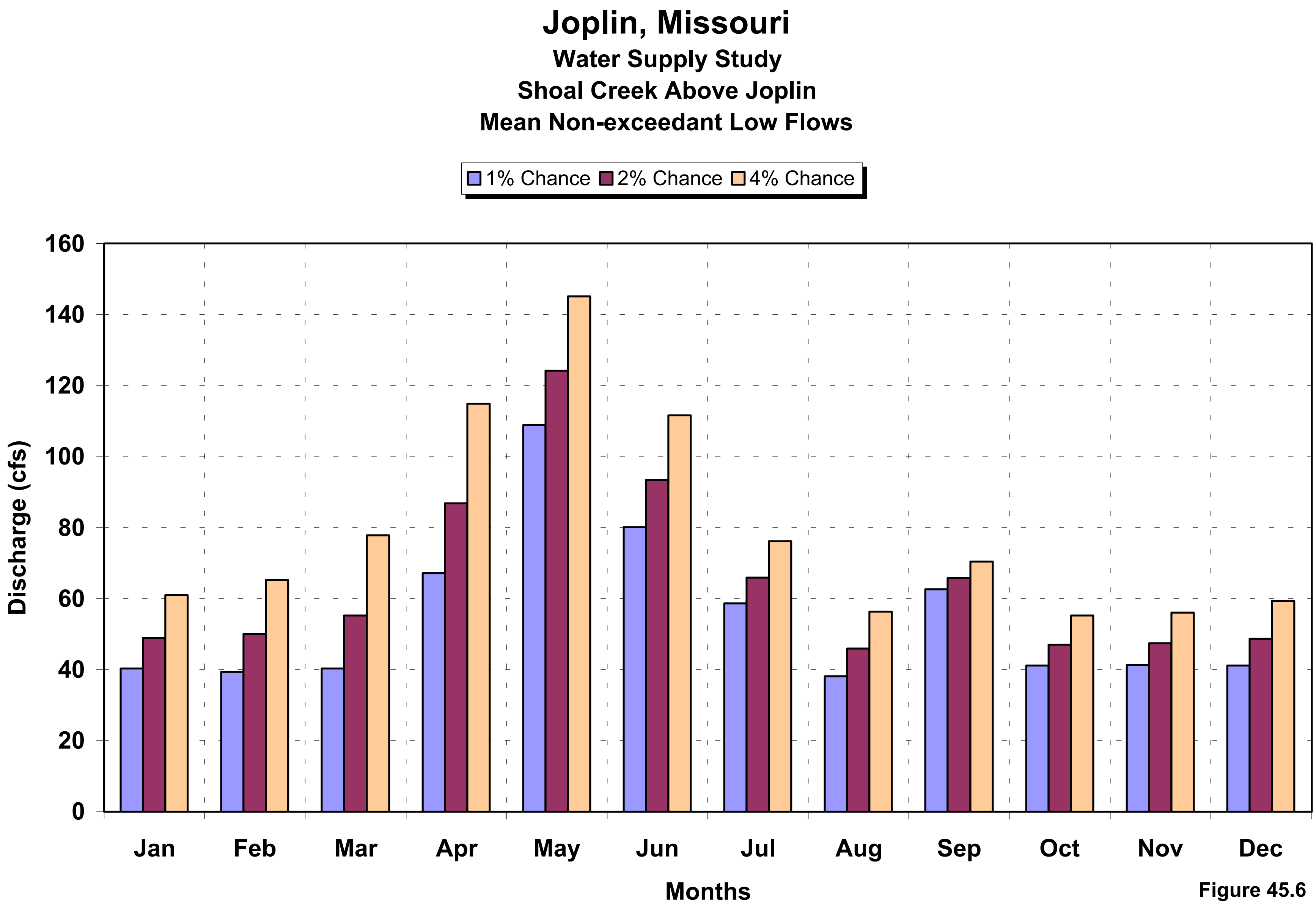

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Mean Non-exceedant Low Flows
1% Chance
2% Chance
4% Chance
Discharge (cfs)
0
20
40
60
80
100
120
140
160
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 45.6

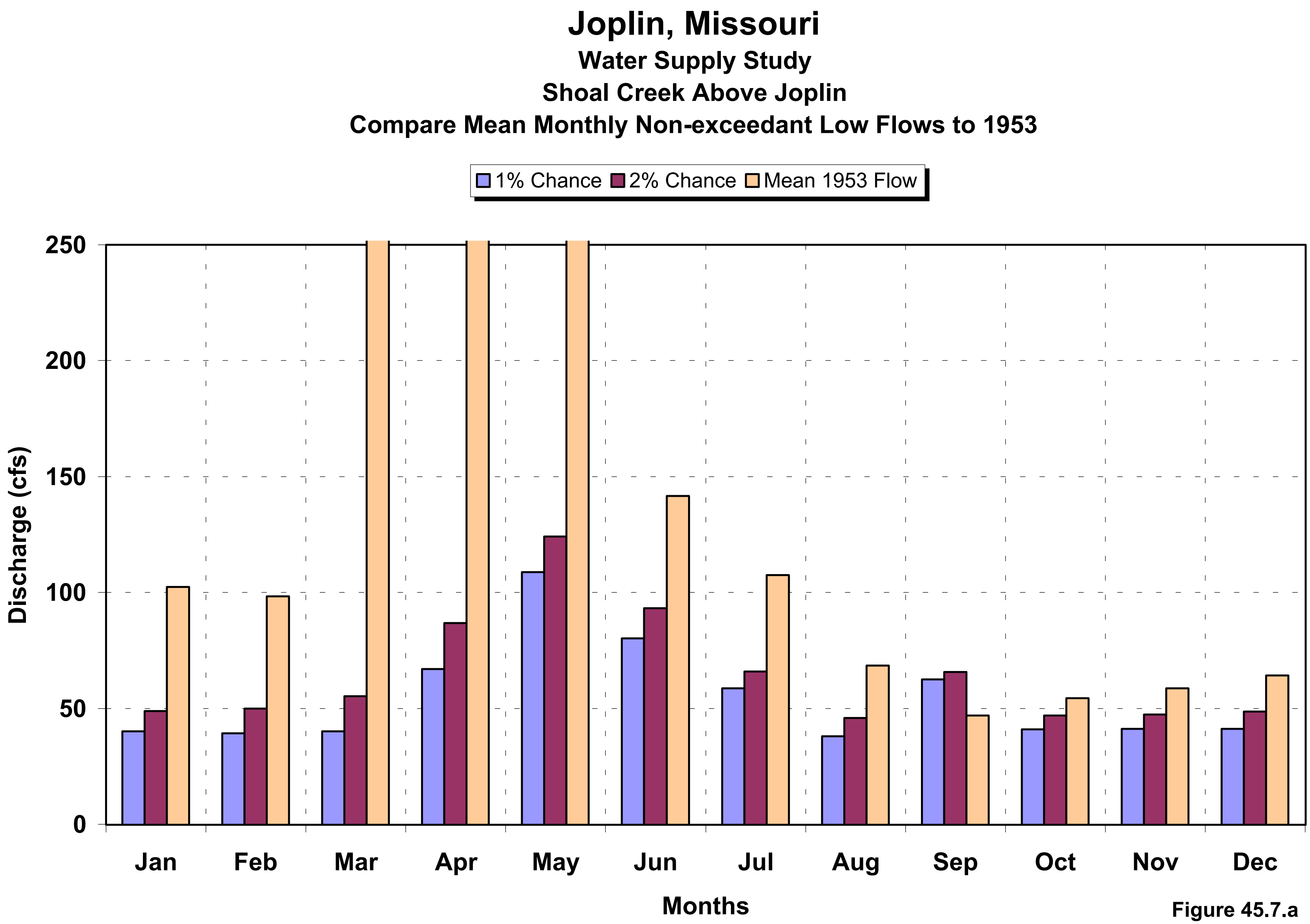

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Compare Mean Monthly Non-exceedant Low Flows to 1953
1% Chance
2% Chance
Mean 1953 Flow
Discharge (cfs)
0
50
100
150
200
250
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 45.7.a

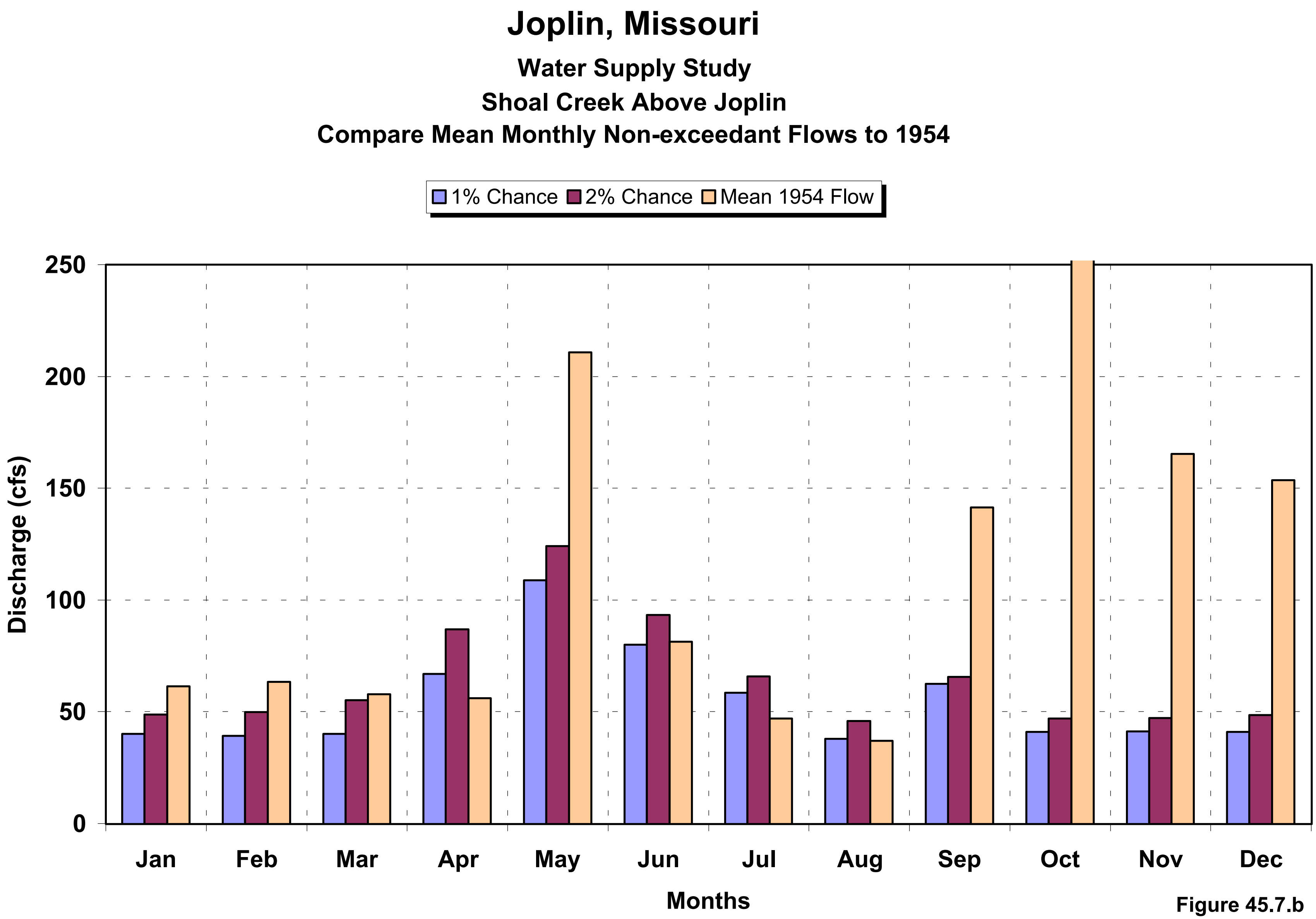

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Compare Mean Monthly Non-exceedant Flows to 1954
1% Chance
2% Chance
Mean 1954 Flow
Discharge (cfs)
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 45.7.b

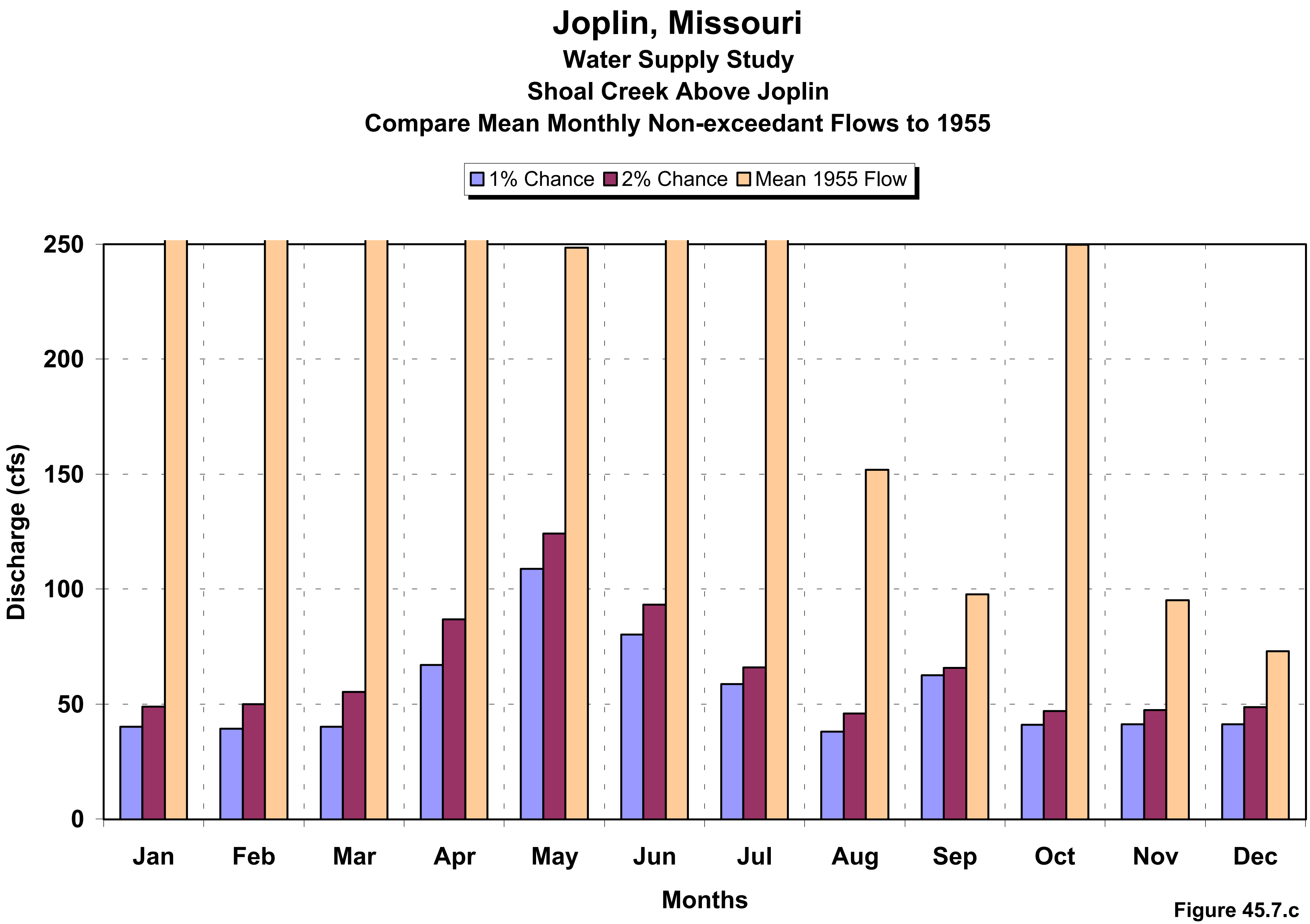

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Compare Mean Monthly Non-exceedant Flows to 1955
1% Chance
2% Chance
Mean 1955 Flow
Discharge (cfs)
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 45.7.c

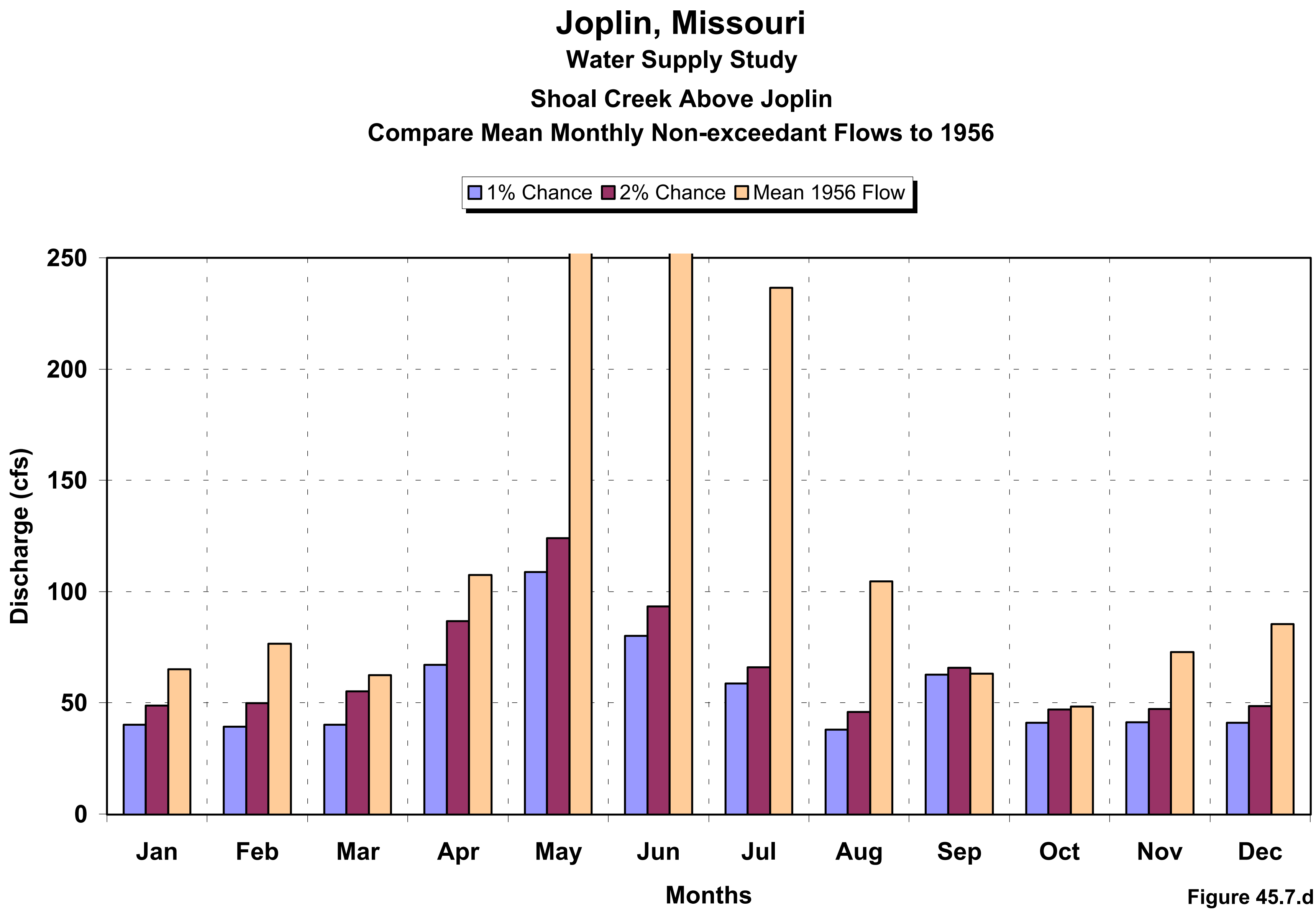

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Compare Mean Monthly Non-exceedant Flows to 1956
1% Chance
2% Chance
Mean 1956 Flow
Discharge (cfs)
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 45.7.d

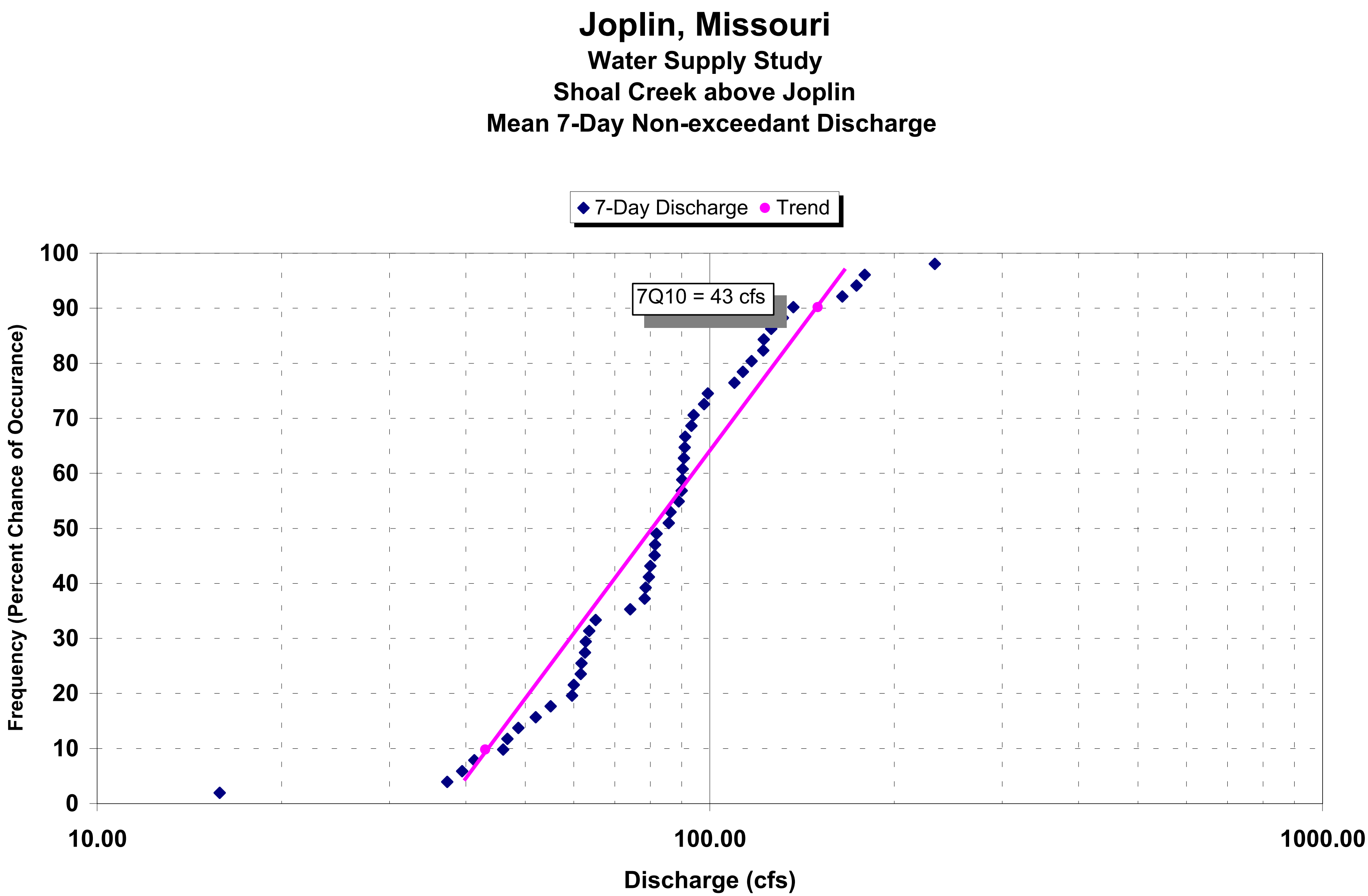
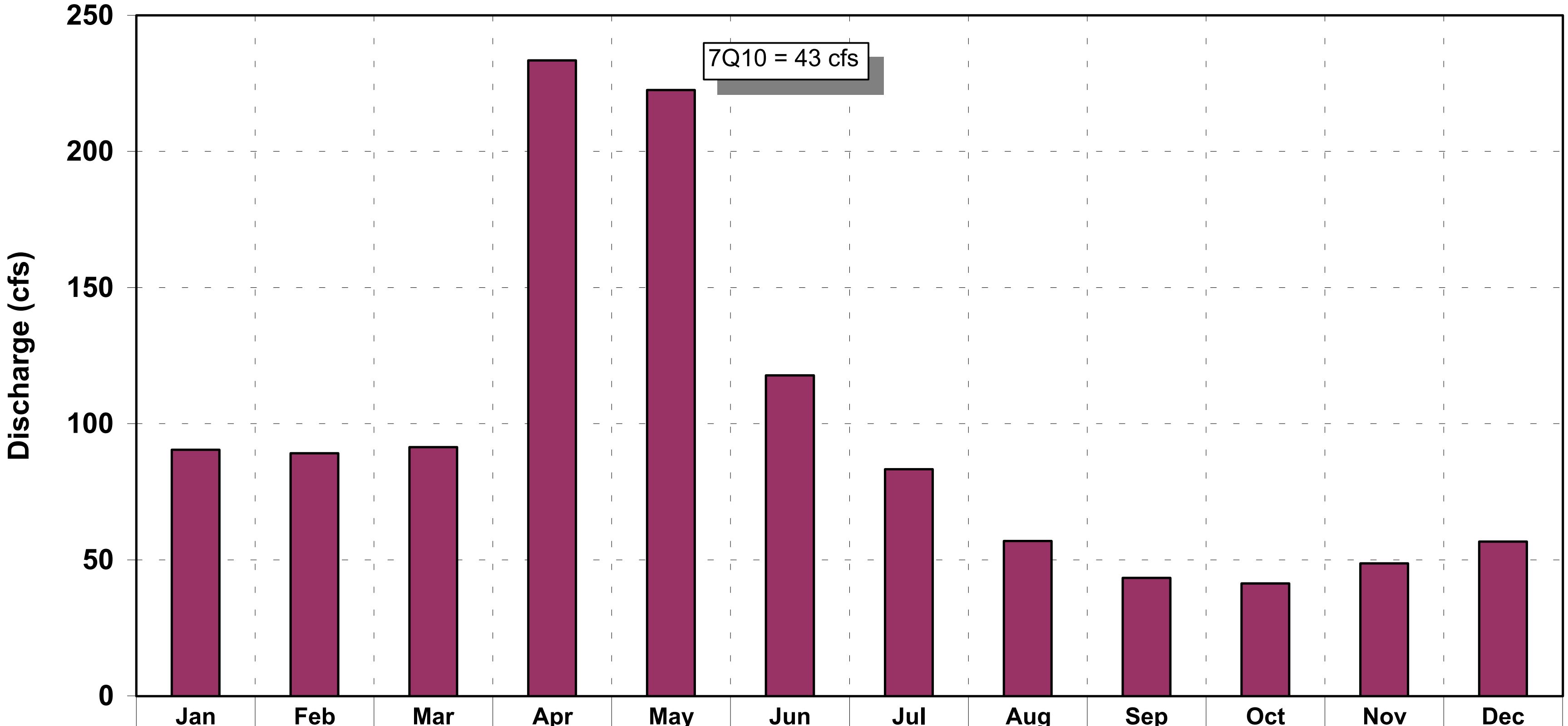

Joplin, Missouri
Water Supply Study
Shoal Creek above Joplin
Mean 7-Day Non-exceedant Discharge
7-Day Discharge
Trend
7Q10 = 43 cfs
100
90
80
70
60
50
40
30
20
10
0
Frequency (Percent Chance of Occurance)
10.00
100.00
1000.00
Discharge (cfs)

Figure 45.8

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Mean 7-day Duration Low Flow for 1953



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1953	90	89	91	233	223	118	83	57	43	41	49	57

Months

Figure 45.9.a

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Mean 7-day Duration Low Flow for 1954

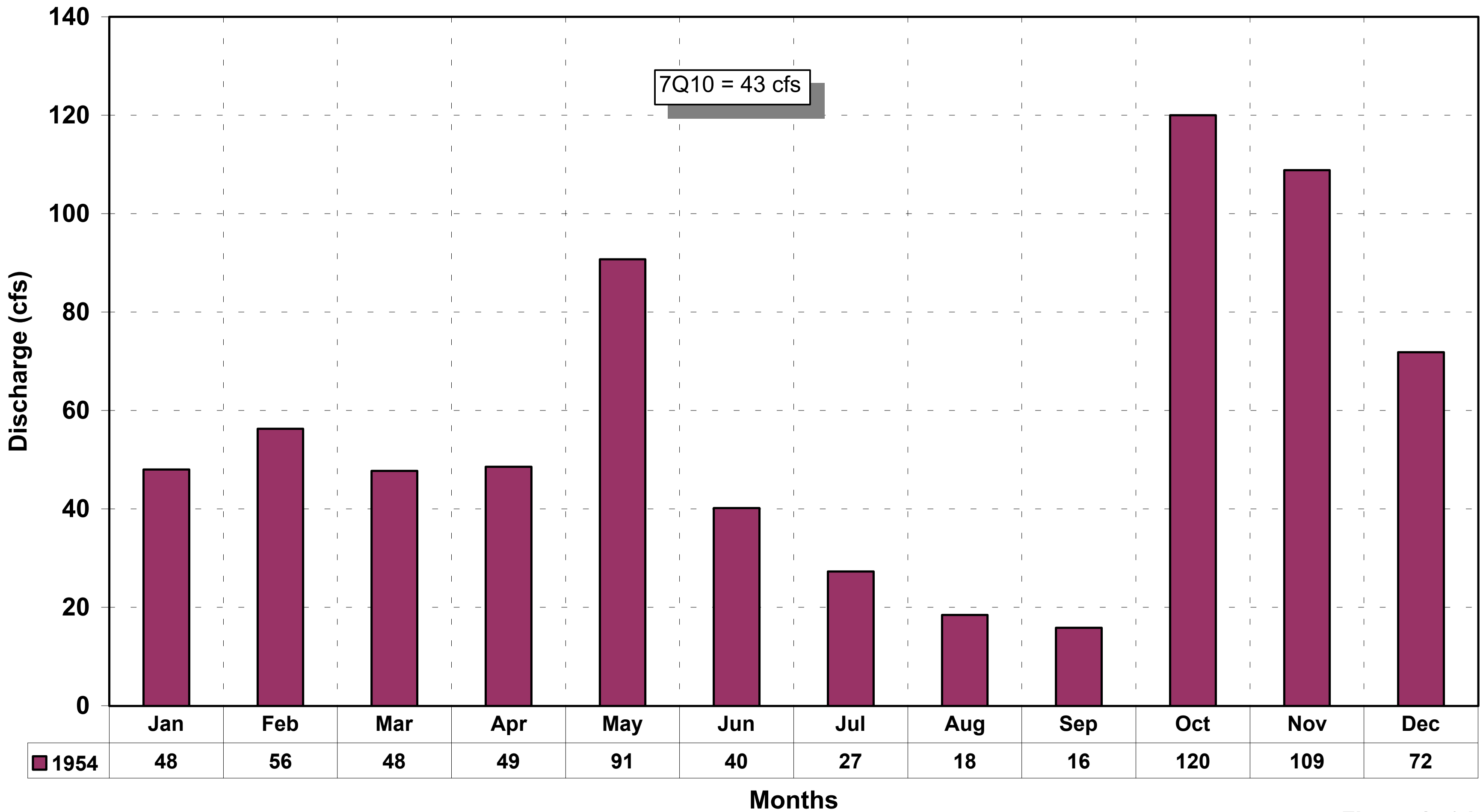
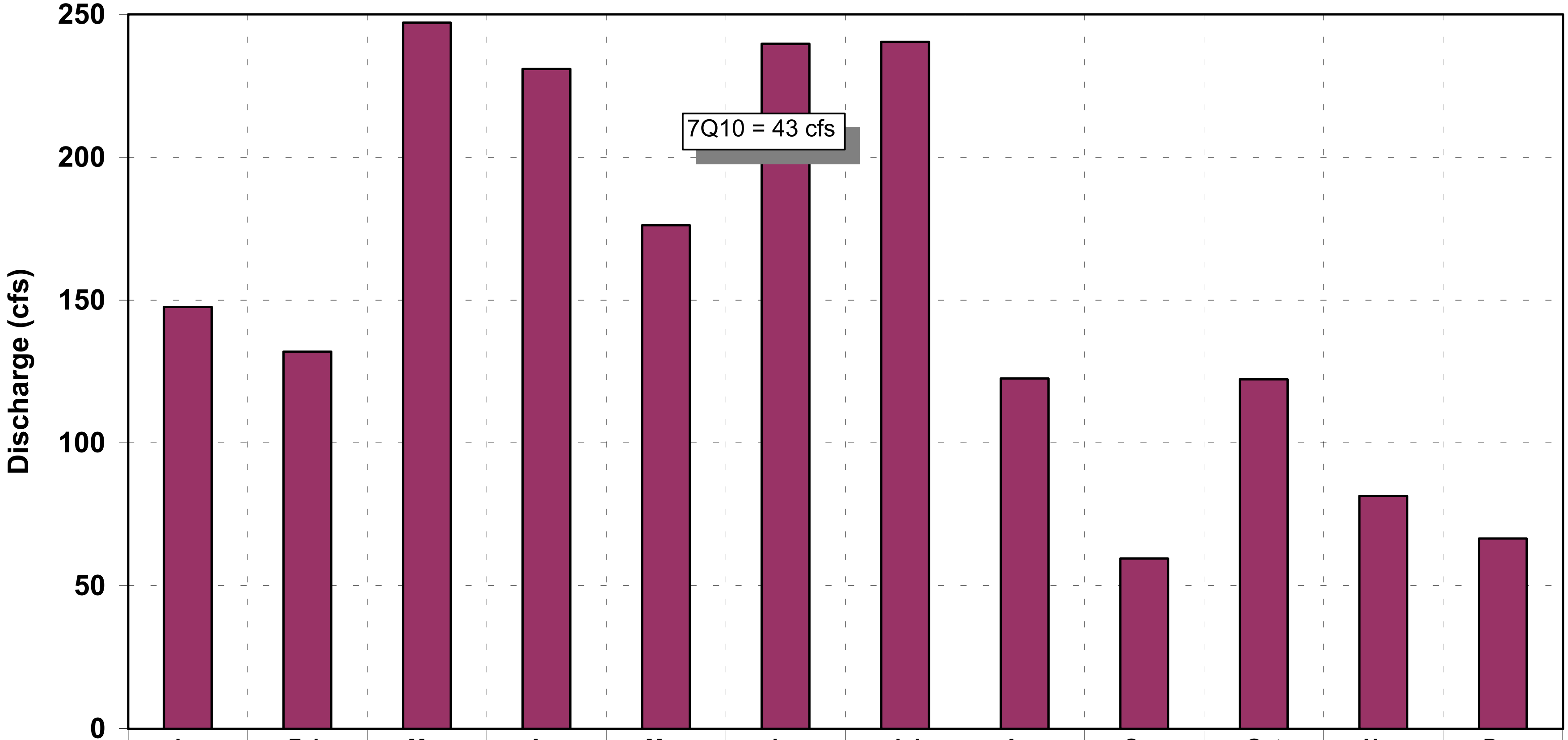


Figure 45.9.b

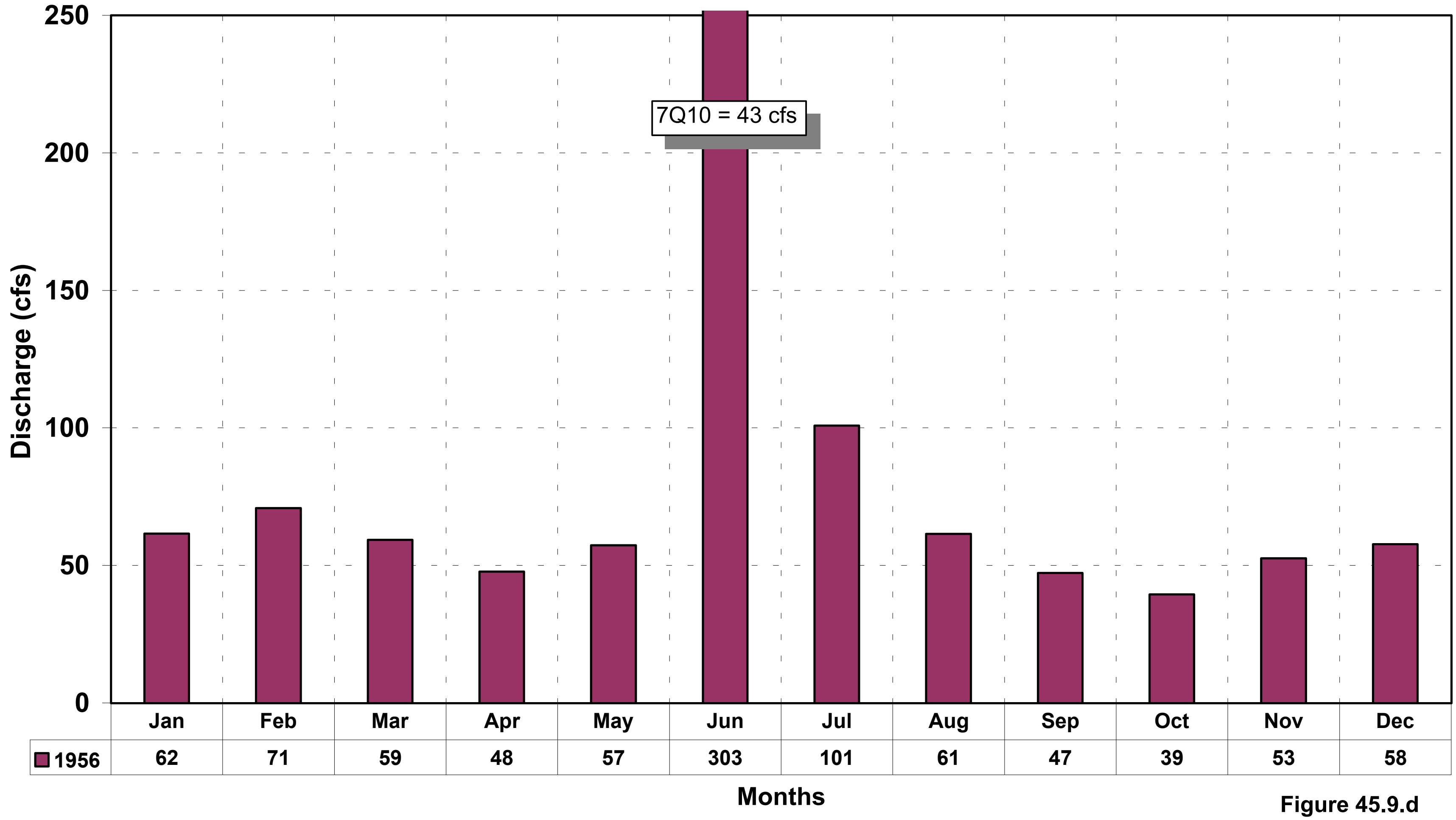
Joplin, Missouri
Water supply Study
Shoal Creek Above Joplin
Mean 7-day Duration Low Flow for 1955



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1955	148	132	247	231	176	240	240	123	60	122	81	67

Figure 45.9.c

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
Mean 7-day duration low flow for 1956



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1956	62	71	59	48	57	303	101	61	47	39	53	58

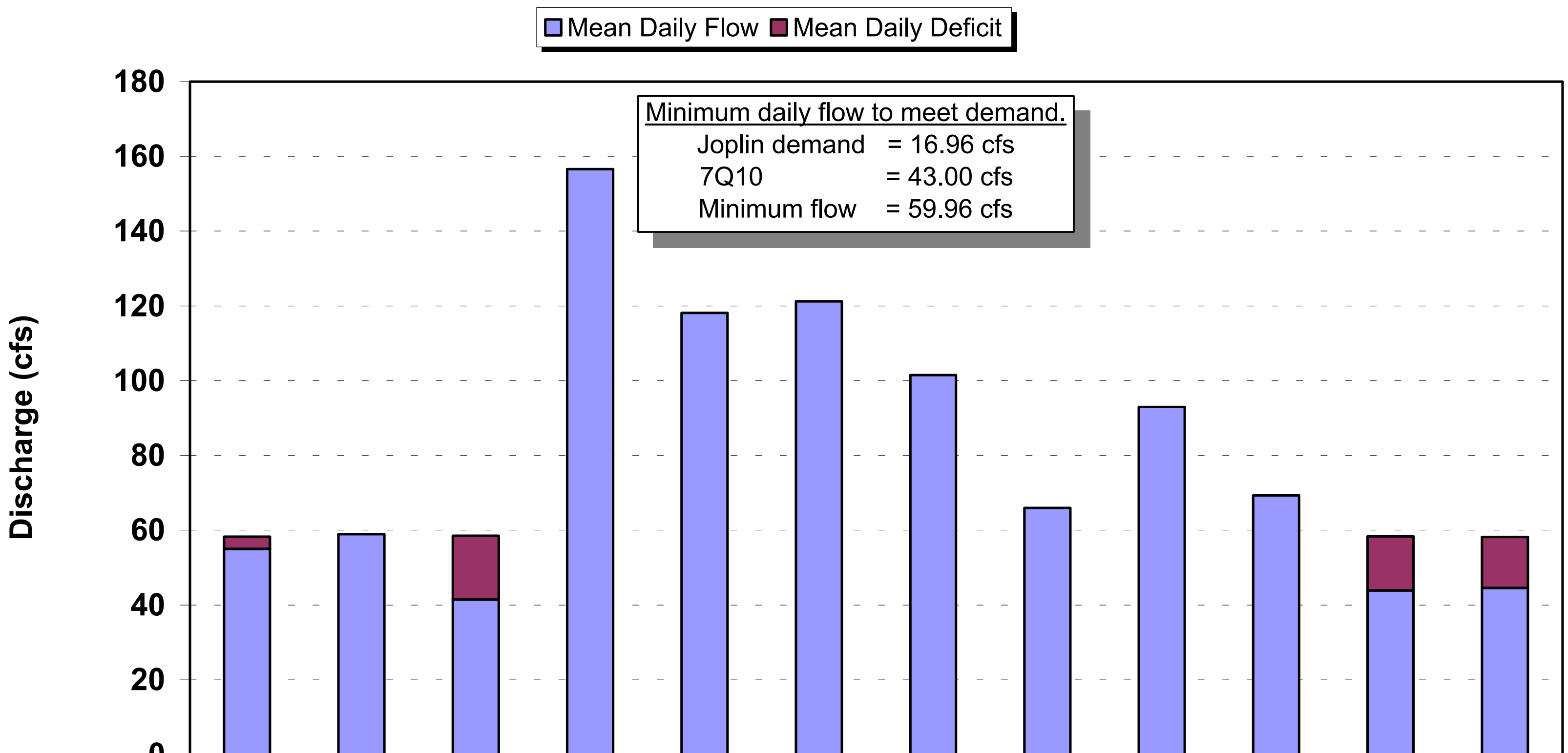
Figure 45.9.d

Joplin, Missouri

Water Supply Study

Shoal Creek Above Joplin

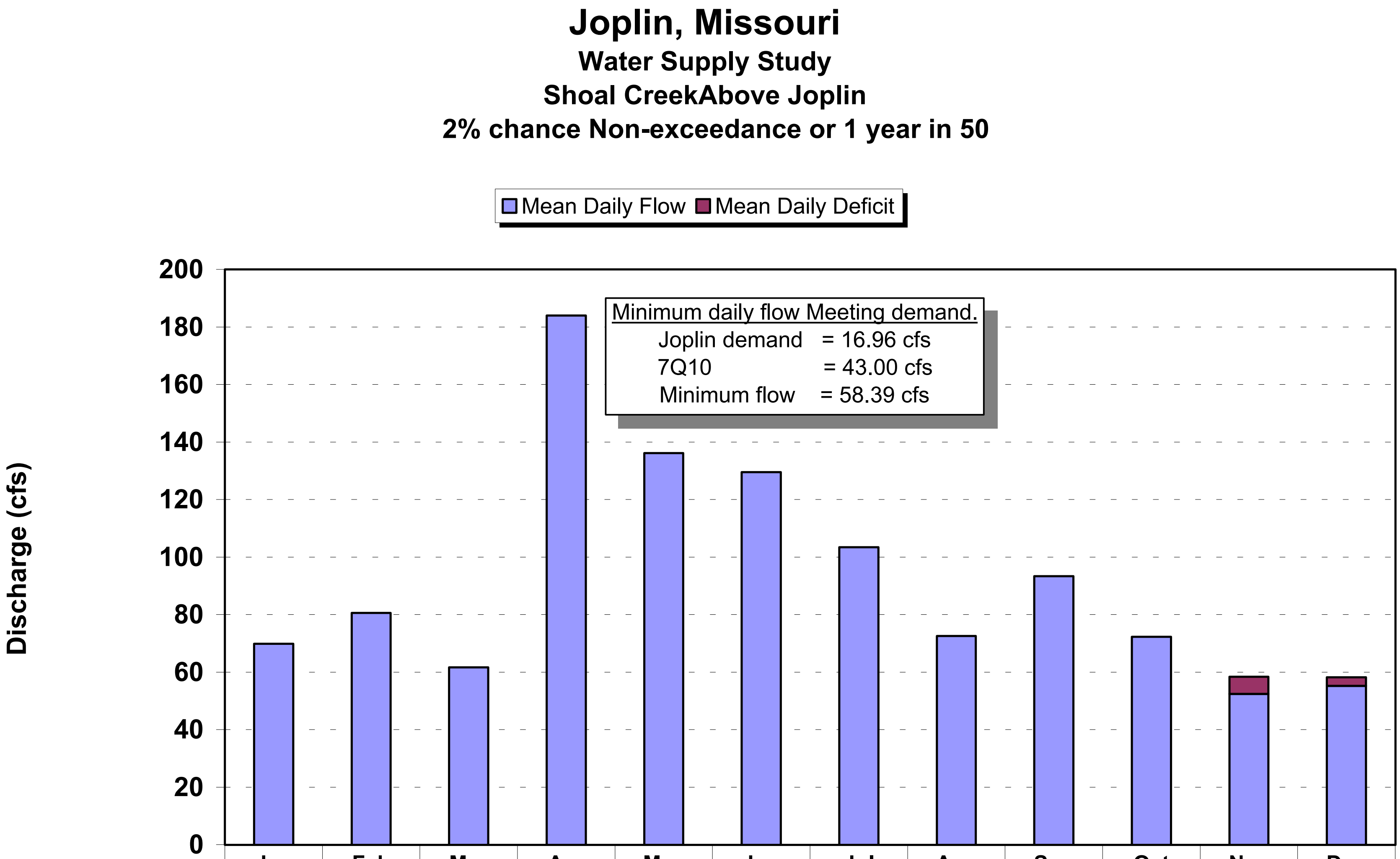
1% chance Non-exceedant Flow or 1 Year in 100 years



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Daily Deficit	3.27	0.00	17.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.49	13.61
Mean Daily Flow	55	58.9	41.5	156.6	118.1	121.2	101.5	66	93	69.3	43.9	44.6

Months

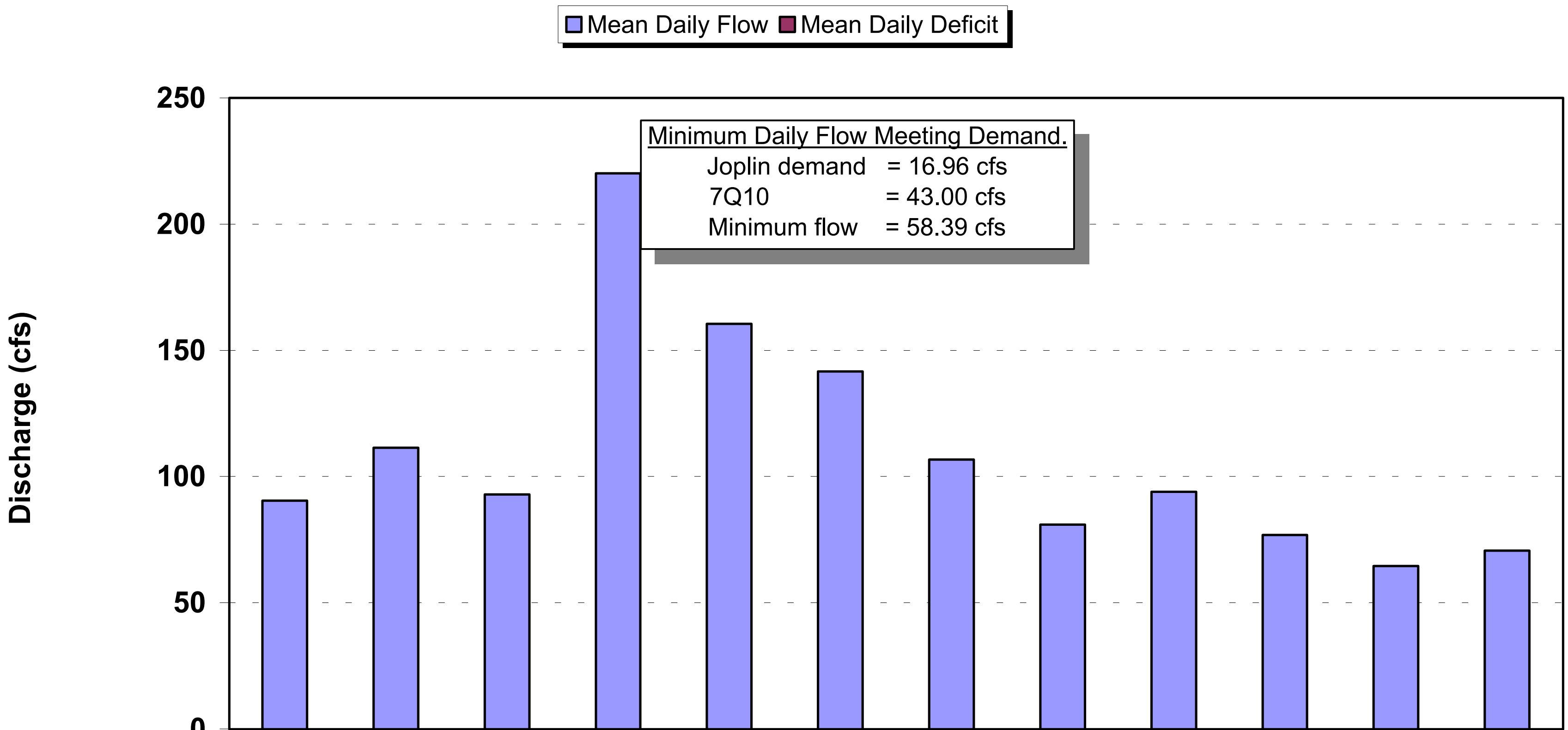
Figure 45.10.a



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Daily Deficit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.99	3.01
Mean Daily Flow	69.8	80.6	61.6	184	136.1	129.5	103.4	72.5	93.3	72.3	52.4	55.2

Figure 45.10.b

Joplin, Missouri
Water Supply Study
Shoal Creek Above Joplin
4% chance Non-exceedance or one year in 25 years



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Daily Deficit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean Daily Flow	90.4	111.4	92.9	220.1	160.5	141.6	106.7	80.9	94	76.9	64.6	70.6

Months

Figure 45.10.c

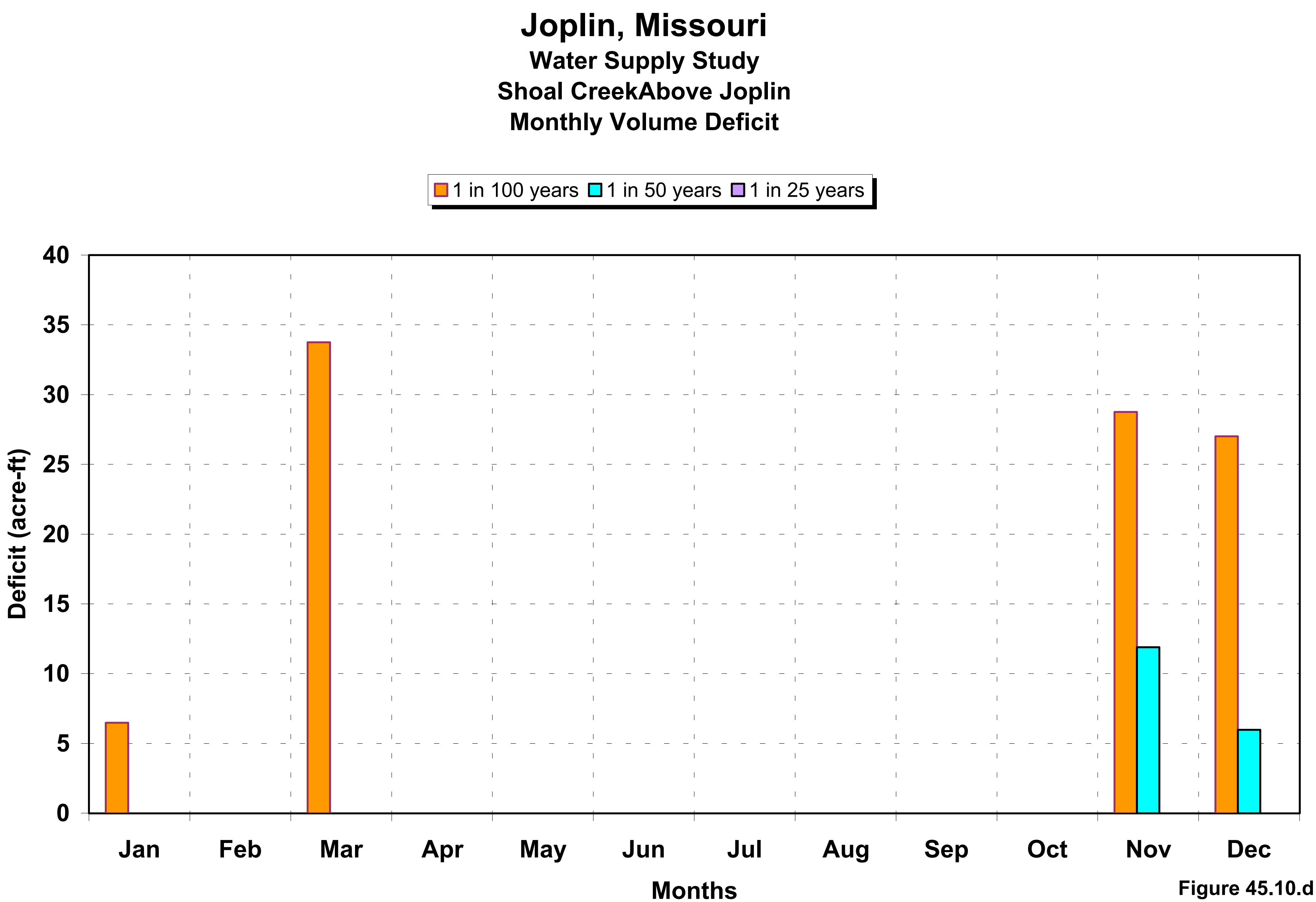


Figure 45.10.d

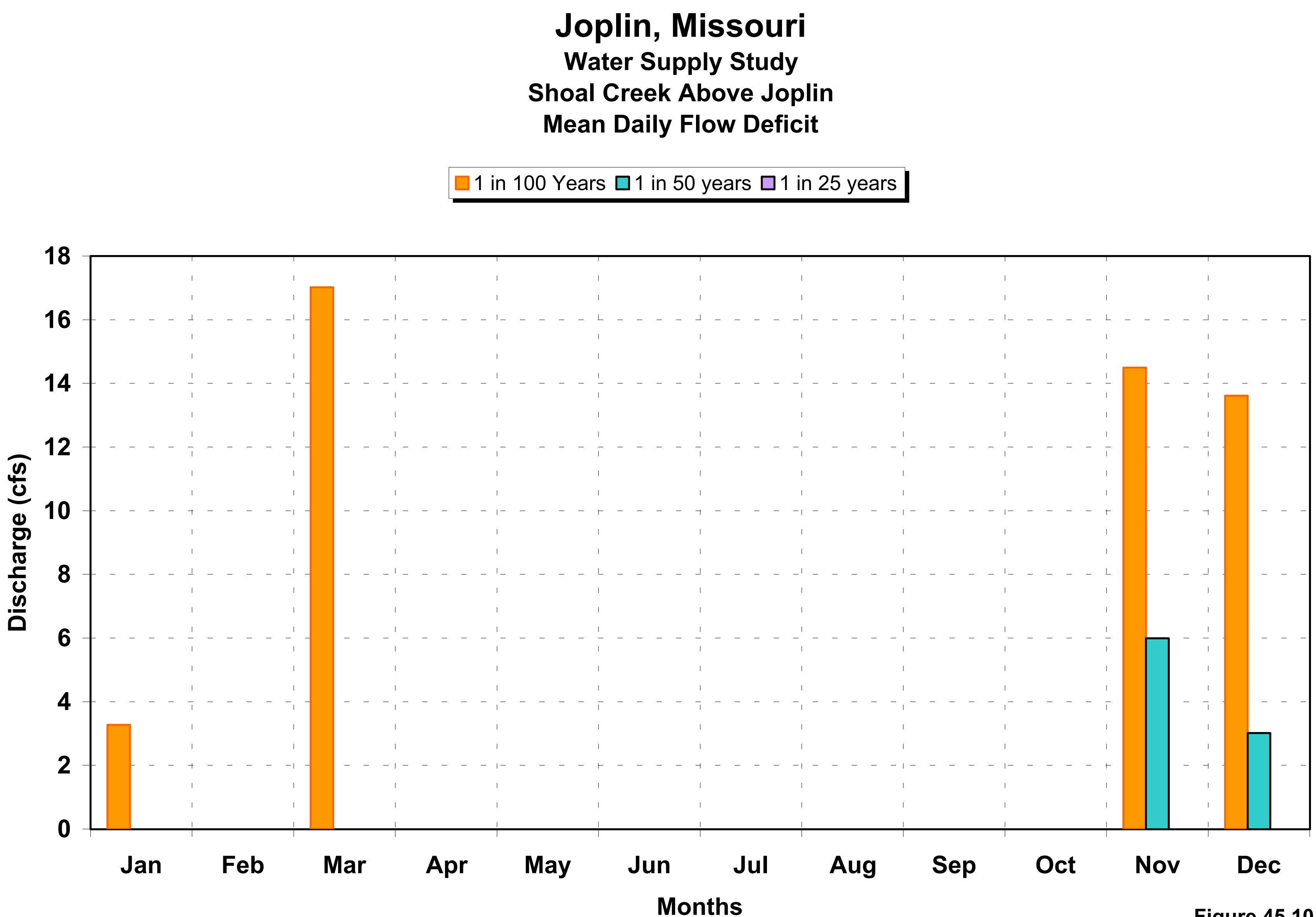


Figure 45.10.e

Perryville, Missouri
Water Supply Study
Saline Creek

Overview

This analysis was made to assess the availability of Perryville's water supply. Perryville obtains their water supply from two sources, Saline Creek and three wells. In year 2000, water use totaled 414,459,000 gallons from both sources, 289,448,000 gallons from Saline Creek and 125,011,000 gallons from the wells. This report addresses the stream flow in Saline creek.

Perryville has no off channel storage to draw upon during periods of low flow, they must rely on their three wells. The drainage area at the creek intake for Perryville is 55.83 square miles. In the year 2000 Perryville used 1.14 million gallons per minute (gpm), 0.79 gpm from Saline Creek and 0.34 from wells. Saline Creek intake is located at the southwest side of Perryville. It would be necessary to continuously divert 550 gpm to obtain 0.8 mgd from Saline Creek. Figure 50.1 shows that the long-term trend (1992 through 2001) daily total water use averaged approximately 1.4 mgd in 1992, then in 1994 water use fell to 1.1 mgd and has remained steady since 1994. Water use from Saline Creek is approximately 0.8 mgd, and is 0.3 mgd from the wells.

Stream flow data was obtained from USGS water supply papers. Mean daily discharges were used to analyze stream flow volumes and frequencies. Continuous records have been kept from 1941 through 2002. For this report, all statistical determinations were made using the Log Pearson type III method as described in Water Resource Council bulletin 17B.

Drought Assessment:

Annual precipitation amounts for most of Missouri have been increasing during the last 50 years. This is shown in the state water plan. The study was recently made for the state by Steve Hu (former state climatologist at University of Missouri) to update climate data. Figure 50.2 illustrates the precipitation trend at Perryville. Annual rainfall at Perryville varies from a low of 25.3 inches in 1953 to a high of 37.4 inches in 1984. Annual rainfall at Perryville does not show the trend to be increasing significantly as in much of Missouri. Figure 50.3.a shows the effect of annual rainfall on runoff for the period 1950 to 2000. Annual runoff fluctuates from a low of near 1 watershed inch in 1998 to as much as 33.5 inches in 1984. Figure 50.3.b shows the runoff in terms of mean annual cubic feet per second (cfs).

Base flow separation was made using the USGS computer program HYSEP. HYSEP separates the base flow hydrograph from the total hydrograph. This analysis was made to estimate sustained flow, in order to establish availability of continuous stream flow. Figure 50.4.a is the base flow index and is the ratio of base flow to total stream flow. This chart shows the yearly fluctuation in base flow indexes and indicates the trend. The trend has increased slightly from approximately 47 percent of total runoff in 1950 to 52 percent in 2000. About 10 percent increase. Figure 50.4.b displays volume of base flow in terms of watershed inches of runoff. Figure 50.4.c shows the base flow in terms of mean cfs. The trend shows the mean base flow to be about 33 cfs or 21 million gallons per day for year 2000.

Mean seven-day duration annual low flows for 1950 through 2000 were calculated and are shown in figure 50.5. The lowest annual mean 7-day discharge occurred in 1955 with a mean value of 0.55 cfs for the year.

Monthly non-exceedance probabilities for 1%, 2% and 4% chance of occurring were established from stream flow data for the years 1950 through 2000. Figure 50.6 displays the 1%, 2% and 4% Chance mean monthly low flow. The 4% chance indicates discharges to be sufficiently high to allow withdrawal throughout the year.

Stream gauge records show the drought of record to be in the 1950's. The following figures 50.7.a, 50.7.b, 50.7.c, 50.7.d, 50.7.e, and 50.7.f compare the 1%, 2% and 4% chance mean monthly non-exceedance flows (low flow) to measured flows for 1952 through 1957. September mean flows tended to be the lowest in all years. In 1953, 1955, and 1956 the monthly mean flows were approximately 1 cfs.

To assure that water quality standards are met most of the time, the mixing zone flow is based on the seven-day average low flow that has a recurrence interval of once in 10 years (7Q10). To determine the rate of flow needed to meet in-stream flow needs, the 7Q10 low flow was determined using the period of record, 1950 through 2000. Figure 50.8 shows the results of the frequency analysis to be 1 cfs. For purposes of diverting water from the creek, discharge needed to exceed 1 cfs plus the diversion rate.

Additional comparisons for the 1950's drought were made using the mean 7-day low flow for examining a shorter duration. These comparisons are shown in figures 50.9.a through 50.9.f. These figures show that the critical months for each year are August, September and October. In the 6 years period of 1952 through 1957 there were 5 months that had mean seven-day flows below 7Q10 discharge of 1 cfs. Critical months having mean monthly flows below 2 cfs are:

1952 - All months exceeded 2 cfs.
1953 - August, September and October had less than 1 cfs.
1954 - September had 0.29 cfs with August and July having less than 2 cfs.
1955 - September had 0.55cfs, with August and October having less than 2 cfs.
1956 – August, September and October had less than 1 cfs.
1957 - October mean flow was 2.1 cfs.

Deficits shown in the following displays are the volume shortages necessary to meet the 7Q10 in-stream flow needs. Figure 50.10.a shows non-exceedance probability flows of the 1% chance of occurrence and indicates the stream flow would not supply enough water for diverting to domestic uses while 2 months fell below 7Q10 flow rate. Figure 50.10.b is the 2 percent chance low flows and 4 months with sufficient flow for daily diversions. Figure 50.10.c shows the 4% chance of occurrence is able to provide enough flow for nine months of the year with August, September and October being unable to provide reliable supply.

Stream flow data was obtained from USGS water supply papers. Mean daily discharges were used to analyze stream flow volumes and frequencies. Because Saline Creek does not have a stream gauge, two stream gauges on St. Francis River were examined and results found to be nearly equal when adjusted to a per square mile basis (Figure 50.11.a). These gauges are the long-term gauge on St. Francis River at Patterson, drainage area is 956 square miles and Little St. Francis River at Fredericktown with a drainage area is 90.5 square miles. The upper reaches of Little St. Francis River border the drainage basin of Saline Creek. A comparison of St. Francis River to Black River, drainage area 956 square miles was also made (figure 50.11.b). Adjustments to runoff for Saline Creek were made based on drainage area. Continuous records at the gauge for St. Francis River at Patterson have been recorded for the period 1928 through 2002.

Conclusion:

In year 2000 the city used a total of 414,459,000 gallons of which 289,448,000 gallons came from Saline Creek, resulting in a mean annual withdraw of 1.14 MGD.

The probability of adequate stream flow in Saline Creek during the months of August, September and October is very low. To meet the mean daily demand from the creek of 1.22 cfs plus the in-stream flow requirement of 1 cfs, at least 2.22 cfs would need to be flowing in the stream before pumping. Every month of the year has the possibility of having the 1% chance low flow below that which would allow pumping from the stream. For the 2% chance of occurrence, only the spring months of February, March, April and May could be expected to have mean flows of sufficient quantity to allow pumping. During the months of August, September and October, Saline Creek could not be depended upon to allow pumping, even at the 4% chance low flow range.

Perryville's water demand has remained nearly constant for the period 1994 through 2001.

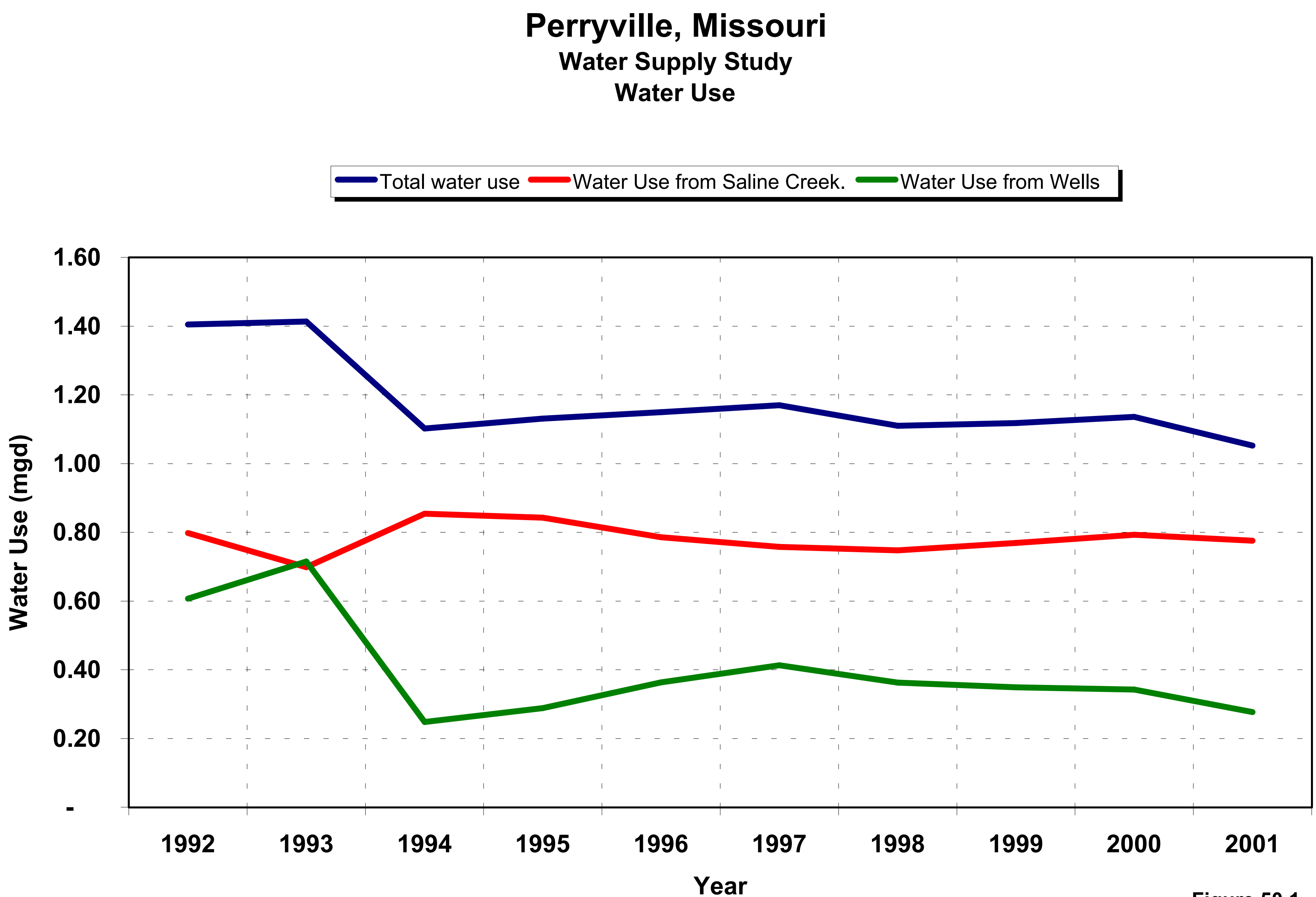

Perryville, Missouri
Water Supply Study
Water Use
Total water use
Water Use from Saline Creek.
Water Use from Wells
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
-
Water Use (mgd)
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 50.1

Perryville, Missouri

Water Supply Study

Saline Creek
Annual Rainfall at Perryville

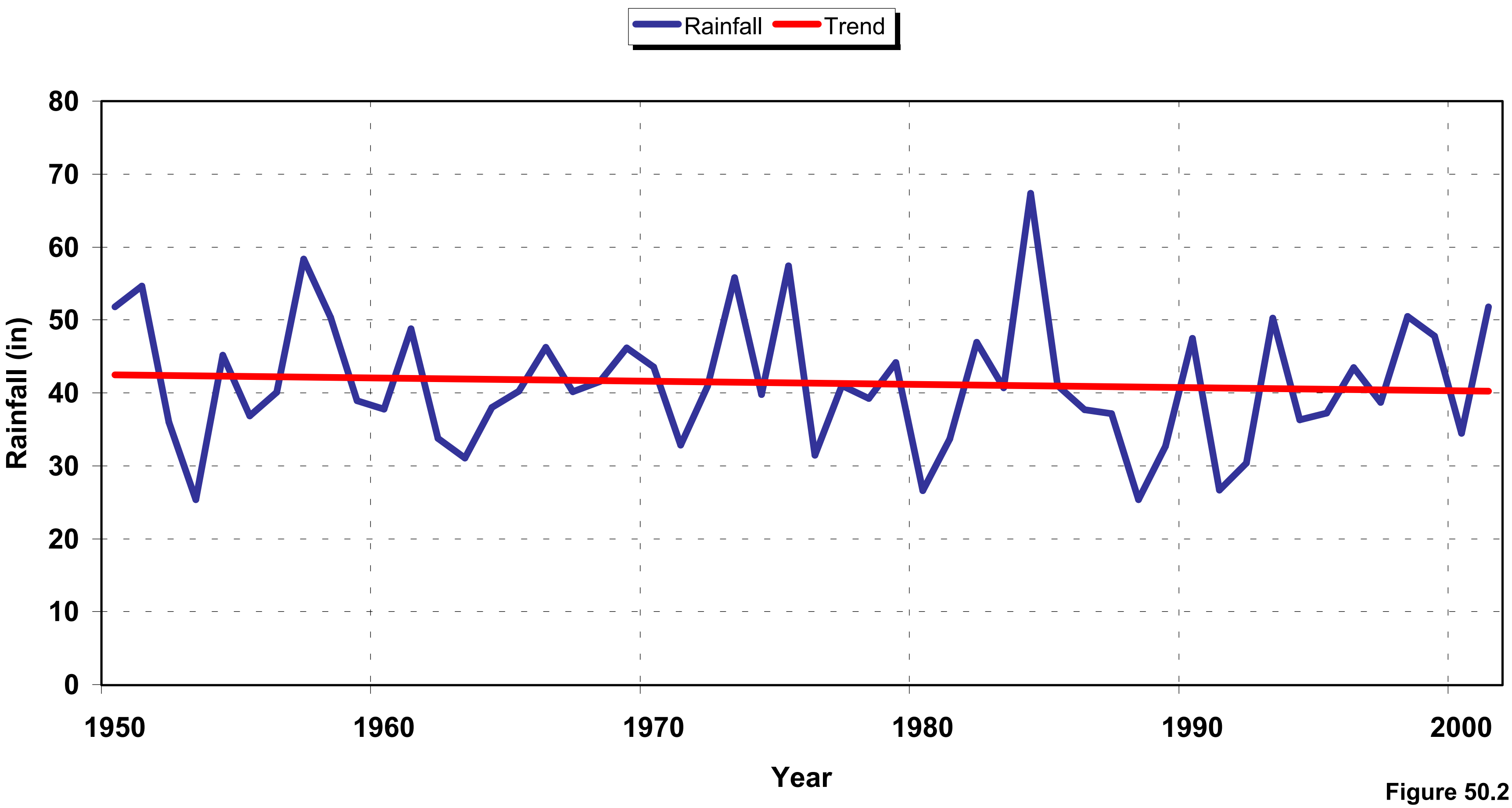


Figure 50.2

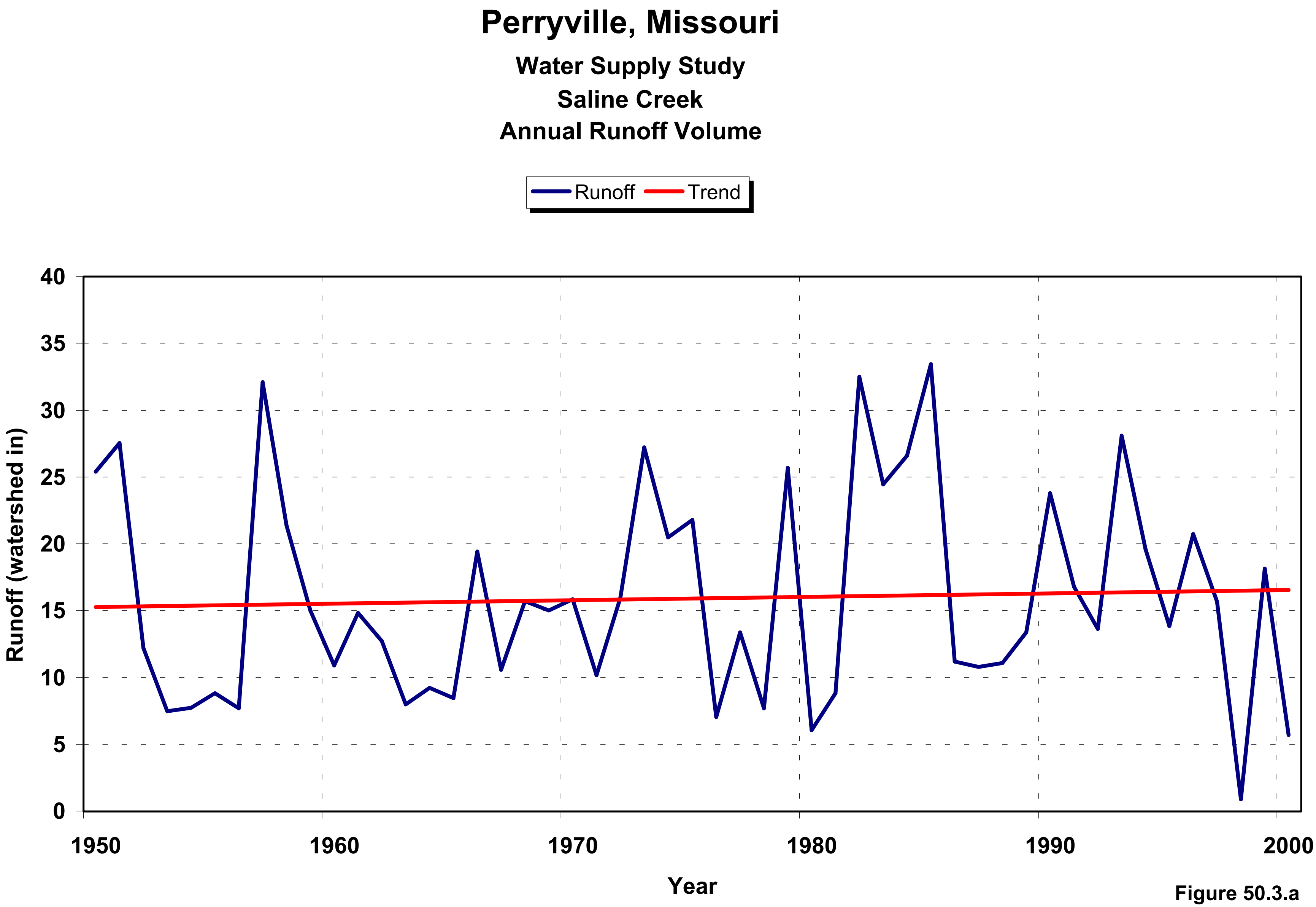

Perryville, Missouri
Water Supply Study
Saline Creek
Annual Runoff Volume
Runoff
Trend
Runoff (watershed in)
40
35
30
25
20
15
10
5
0
1950
1960
1970
1980
1990
2000
Year

Figure 50.3.a

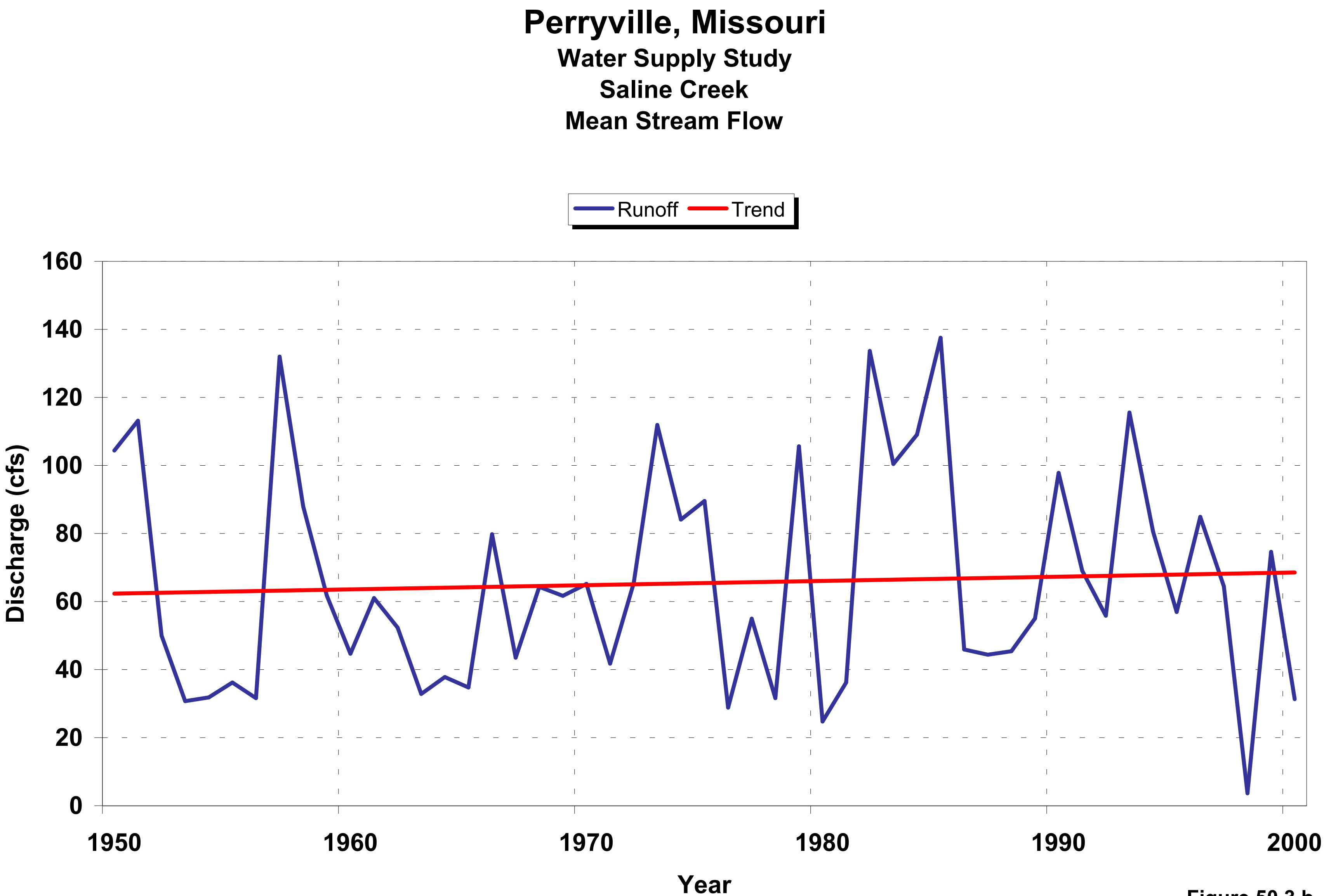

Perryville, Missouri
Water Supply Study
Saline Creek
Mean Stream Flow
Runoff
Trend
Discharge (cfs)
160
140
120
100
80
60
40
20
0
1950
1960
1970
1980
1990
2000
Year

Figure 50.3.b

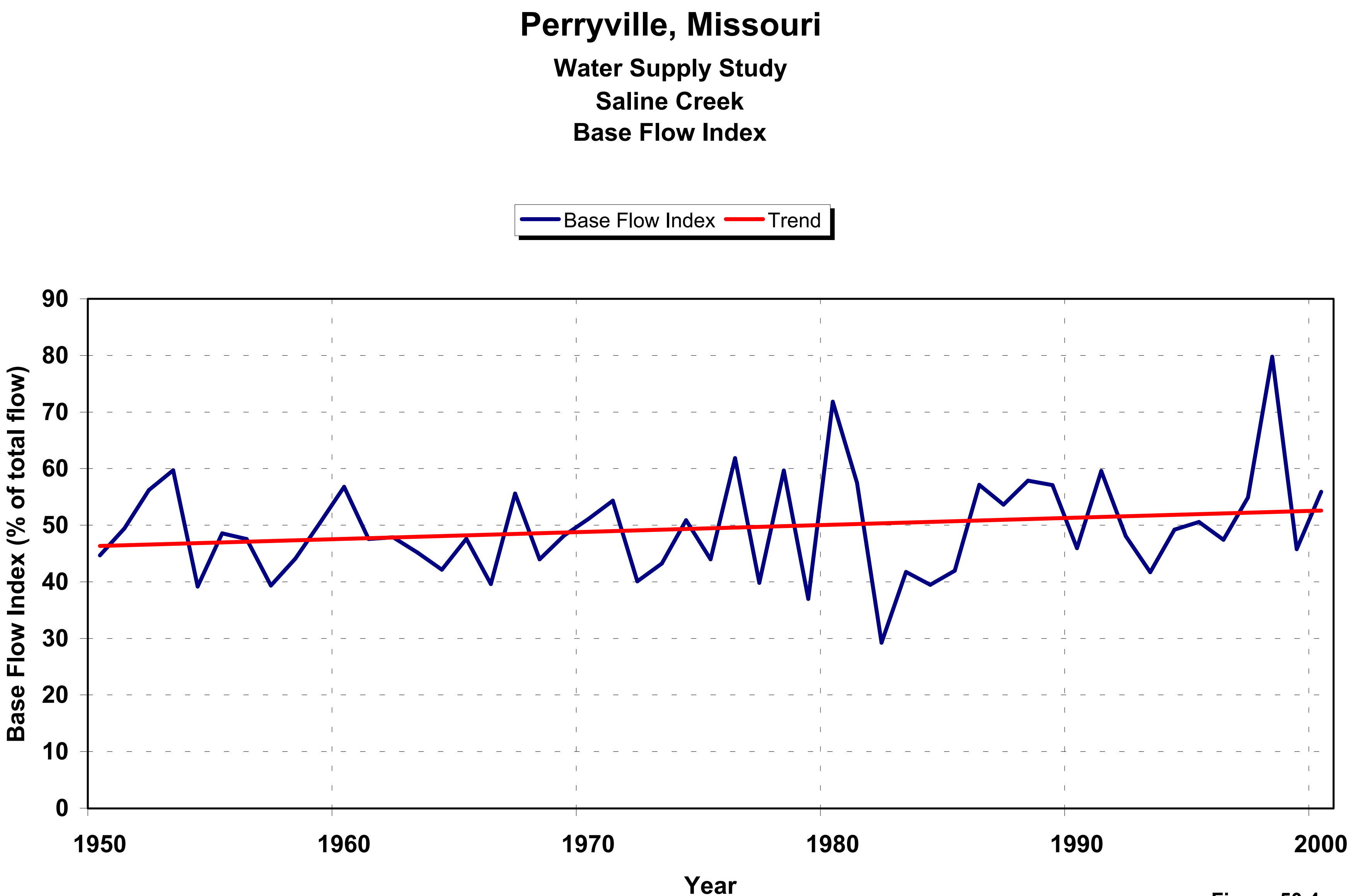

Perryville, Missouri
Water Supply Study
Saline Creek
Base Flow Index
Base Flow Index
Trend
Base Flow Index (% of total flow)
0
10
20
30
40
50
60
70
80
90
1950
1960
1970
1980
1990
2000
Year

Figure 50.4.a

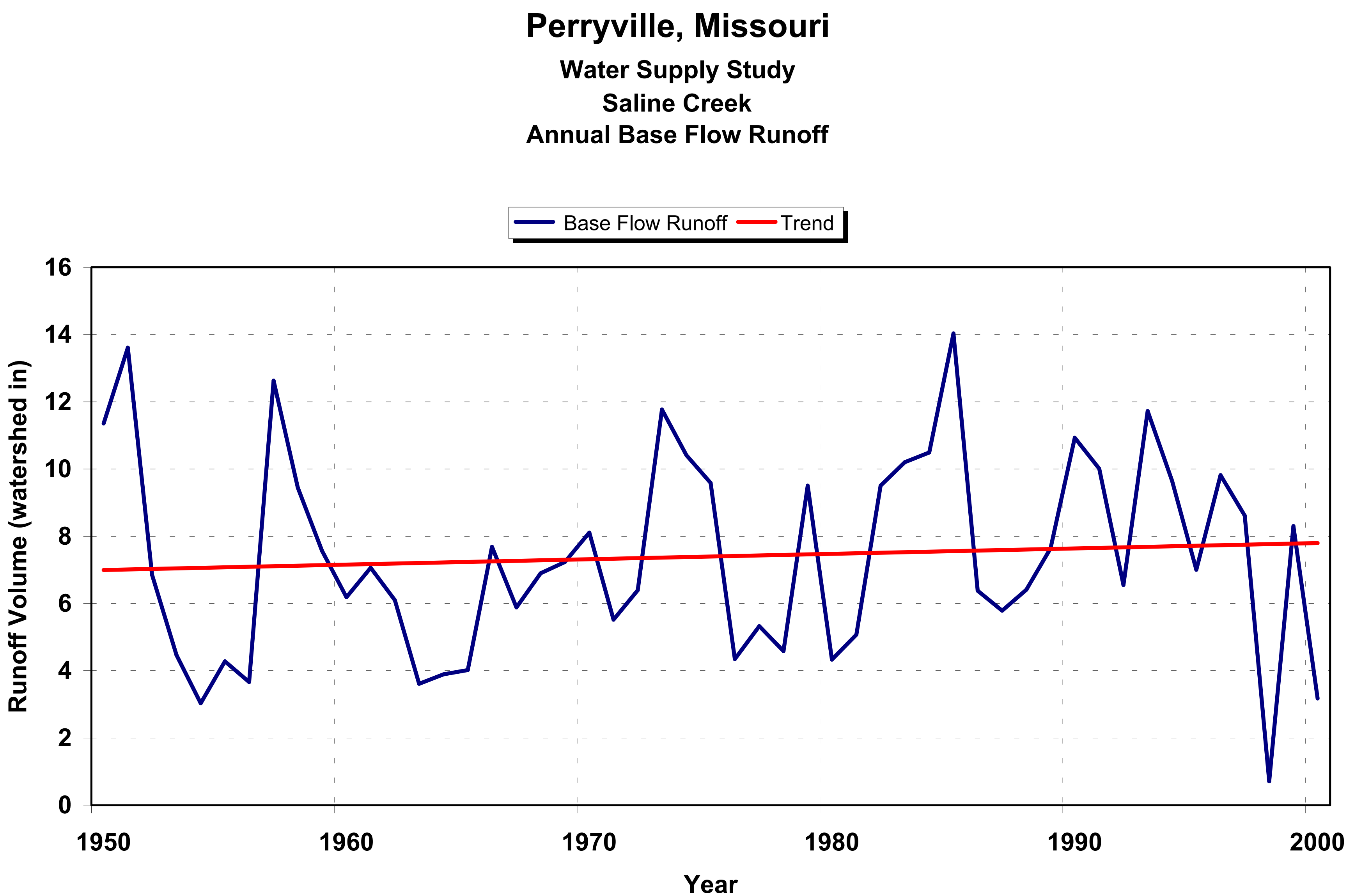

Perryville, Missouri
Water Supply Study
Saline Creek
Annual Base Flow Runoff
Base Flow Runoff
Trend
16
14
12
10
8
6
4
2
0
Runoff Volume (watershed in)
1950
1960
1970
1980
1990
2000
Year

Figure 50.4.b

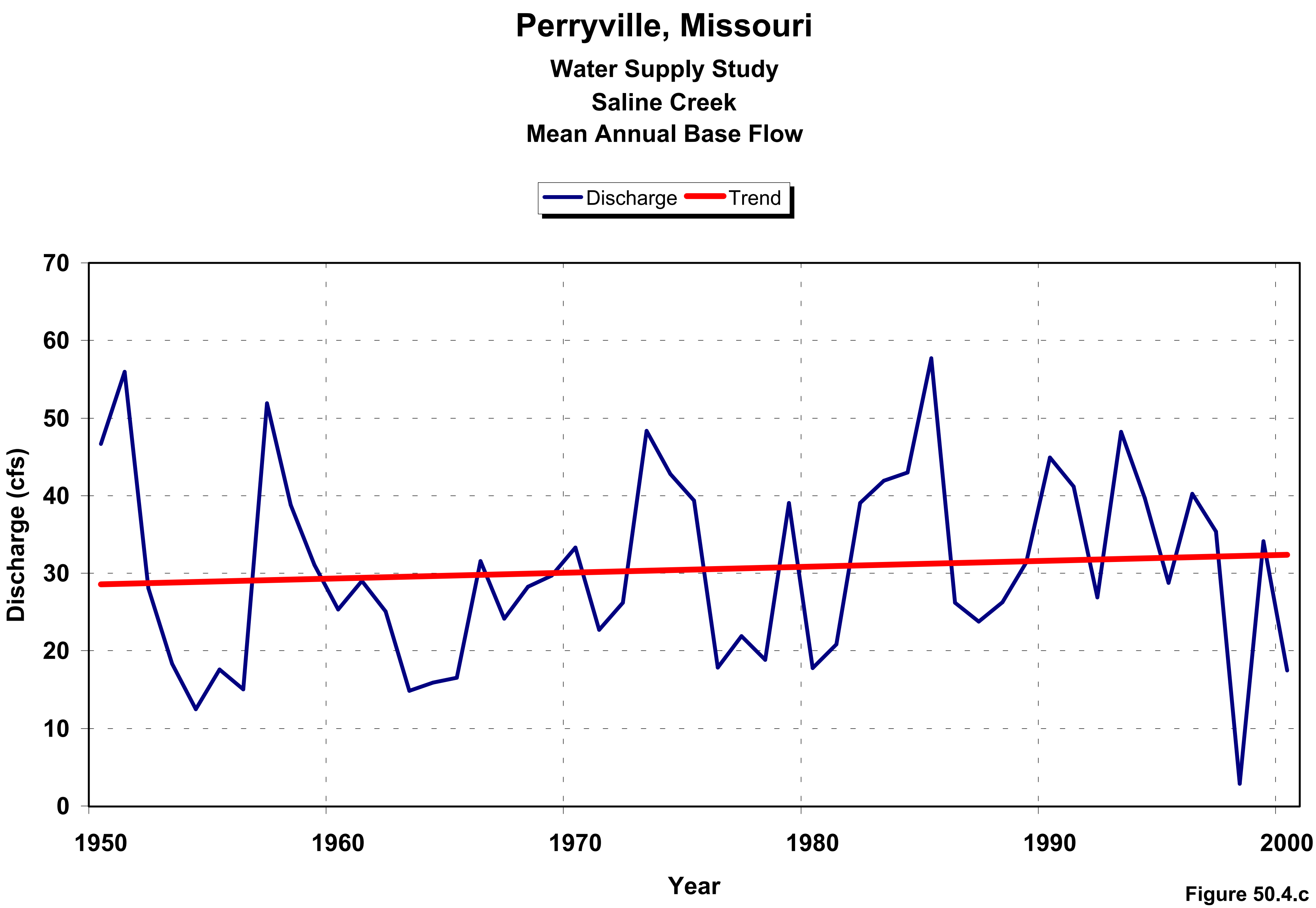

Perryville, Missouri
Water Supply Study
Saline Creek
Mean Annual Base Flow
Discharge
Trend
Discharge (cfs)
70
60
50
40
30
20
10
0
1950
1960
1970
1980
1990
2000
Year

Figure 50.4.c

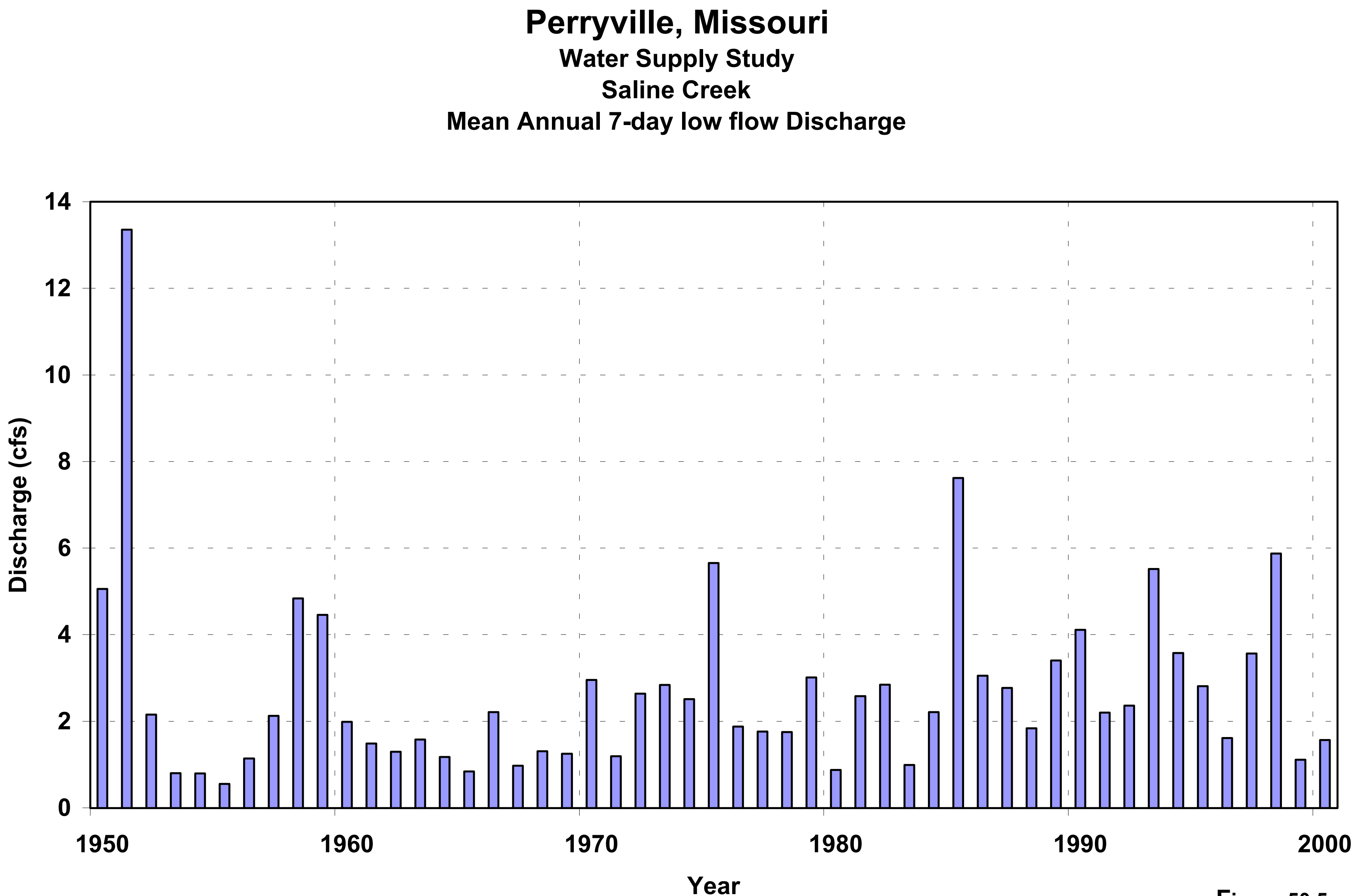

Perryville, Missouri
Water Supply Study
Saline Creek
Mean Annual 7-day low flow Discharge
Discharge (cfs)
0
2
4
6
8
10
12
14
1950
1960
1970
1980
1990
2000
Year

Figure 50.5

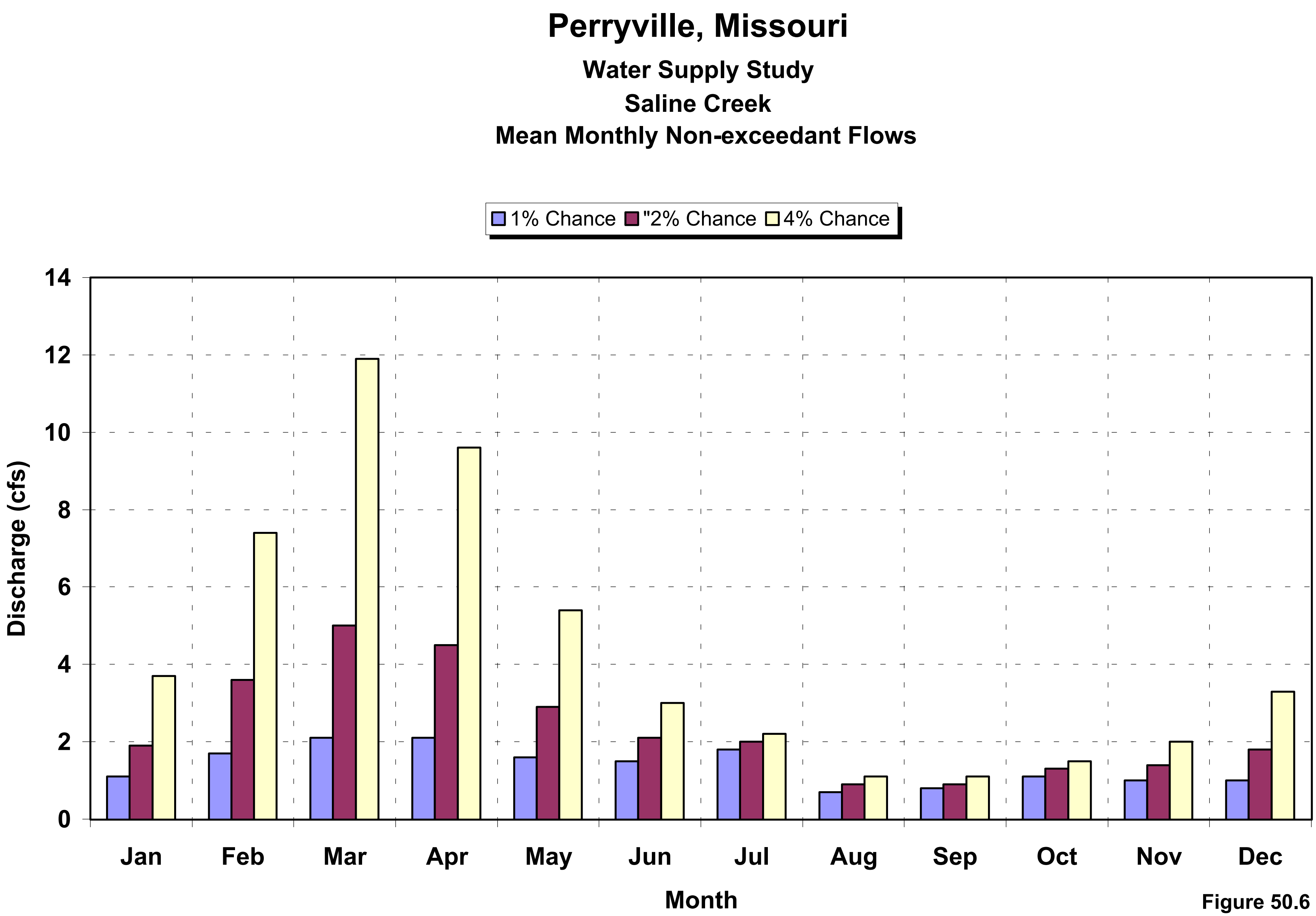

Perryville, Missouri
Water Supply Study
Saline Creek
Mean Monthly Non-exceedant Flows
1% Chance
"2% Chance
4% Chance
Discharge (cfs)
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.6

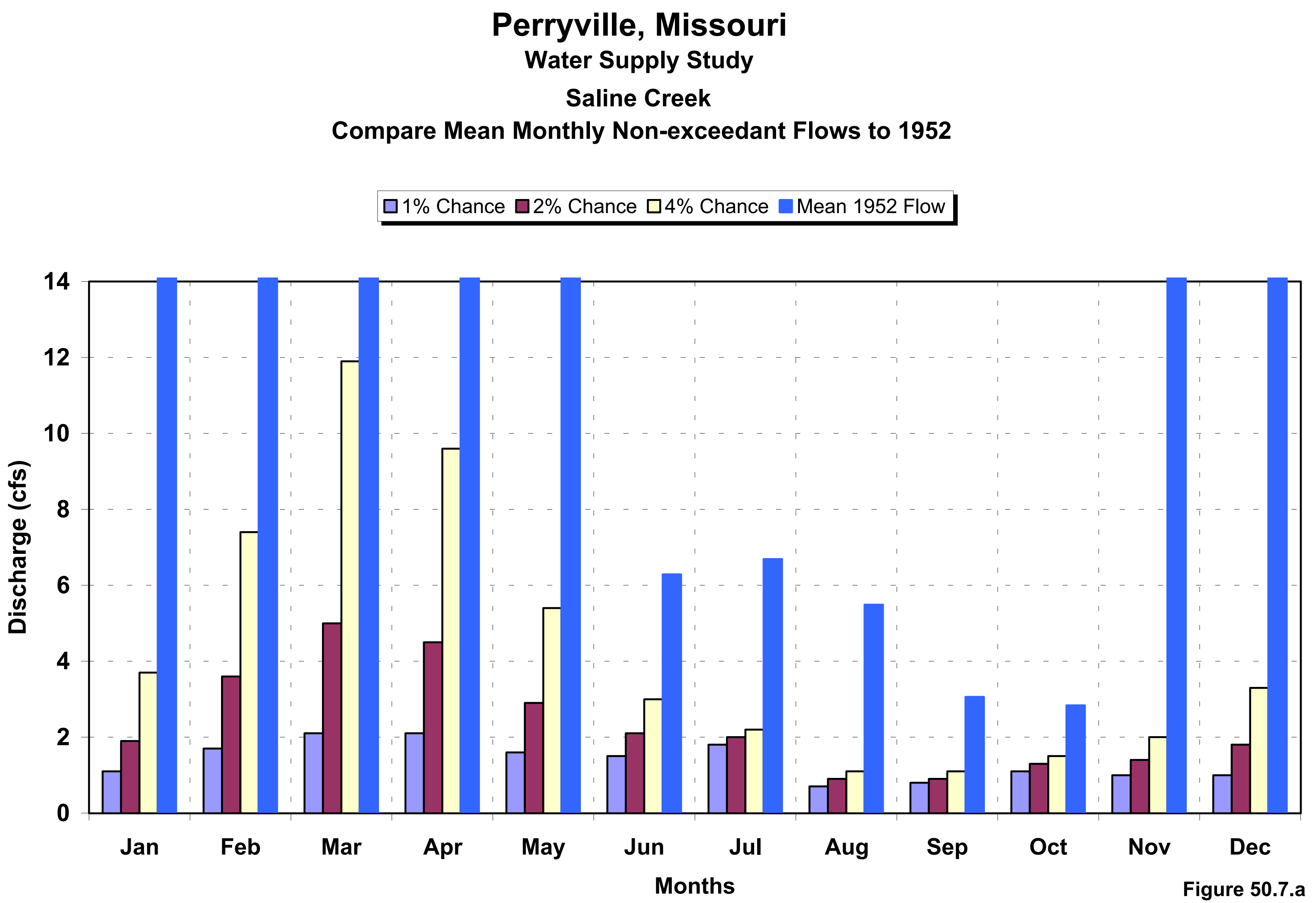

Perryville, Missouri
Water Supply Study
Saline Creek
Compare Mean Monthly Non-exceedant Flows to 1952
1% Chance
2% Chance
4% Chance
Mean 1952 Flow
14
12
10
8
6
4
2
0
Discharge (cfs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 50.7.a

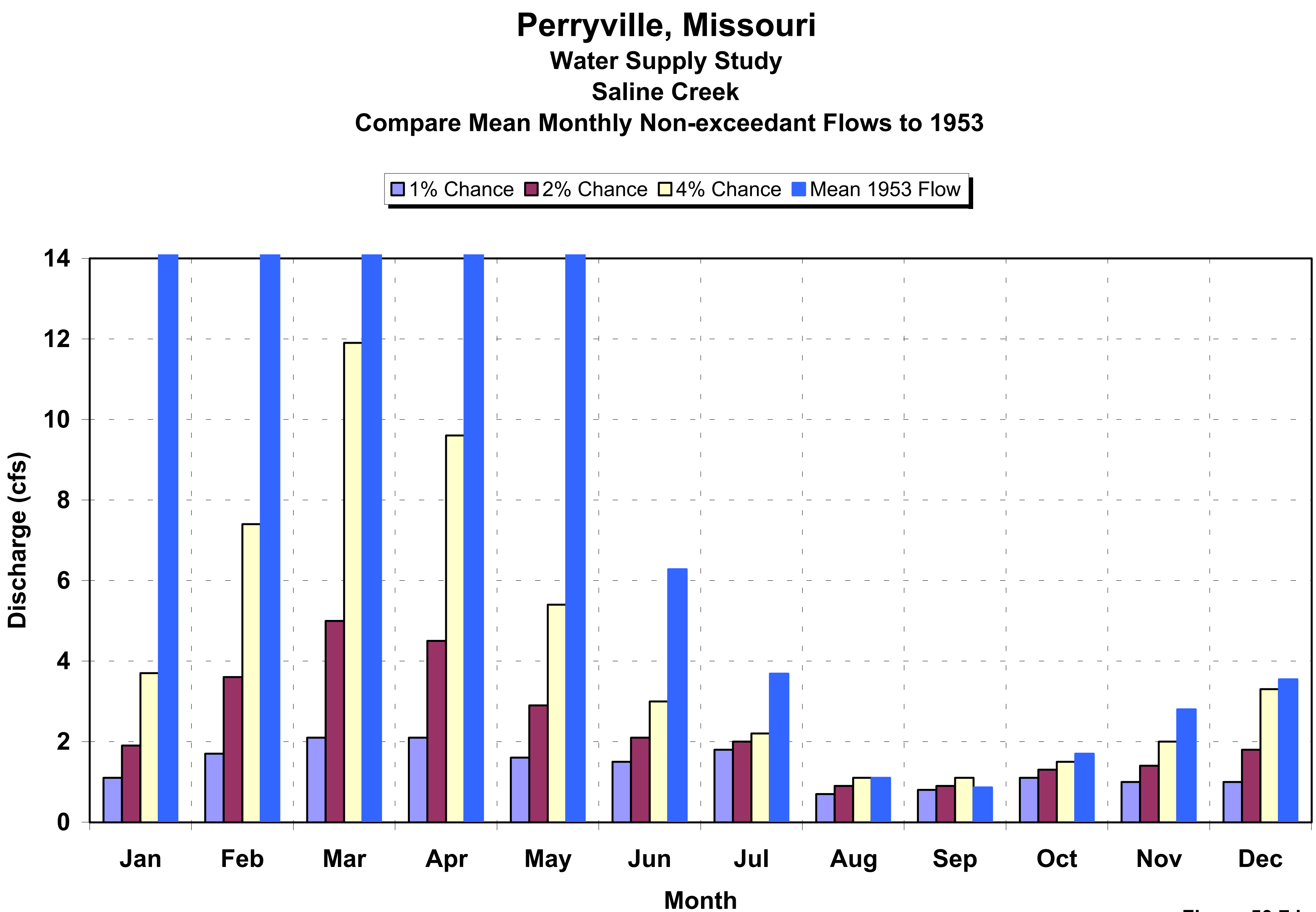

Perryville, Missouri
Water Supply Study
Saline Creek
Compare Mean Monthly Non-exceedant Flows to 1953
1% Chance
2% Chance
4% Chance
Mean 1953 Flow
Discharge (cfs)
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.7.b

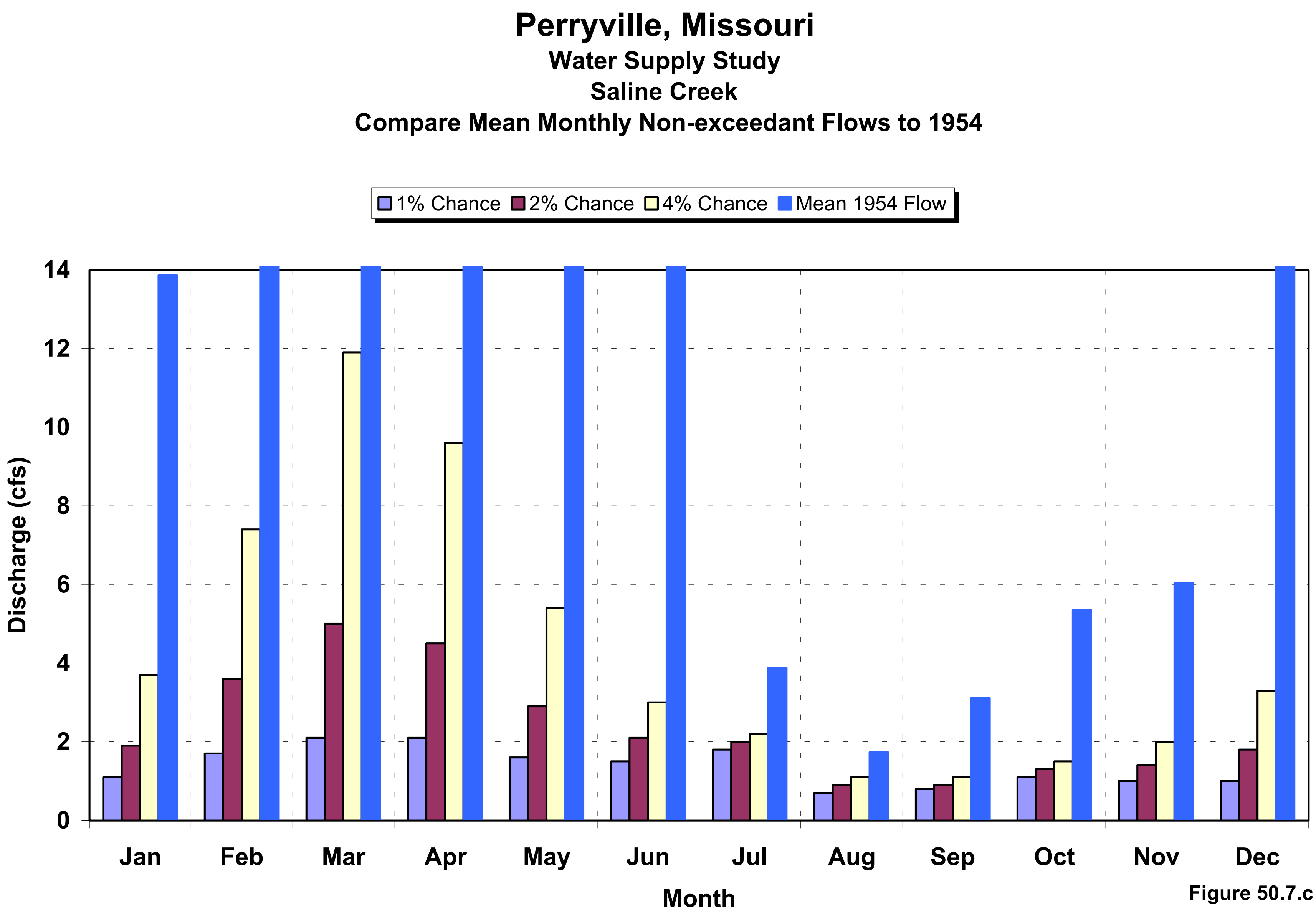

Perryville, Missouri
Water Supply Study
Saline Creek
Compare Mean Monthly Non-exceedant Flows to 1954
1% Chance
2% Chance
4% Chance
Mean 1954 Flow
Discharge (cfs)
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.7.c

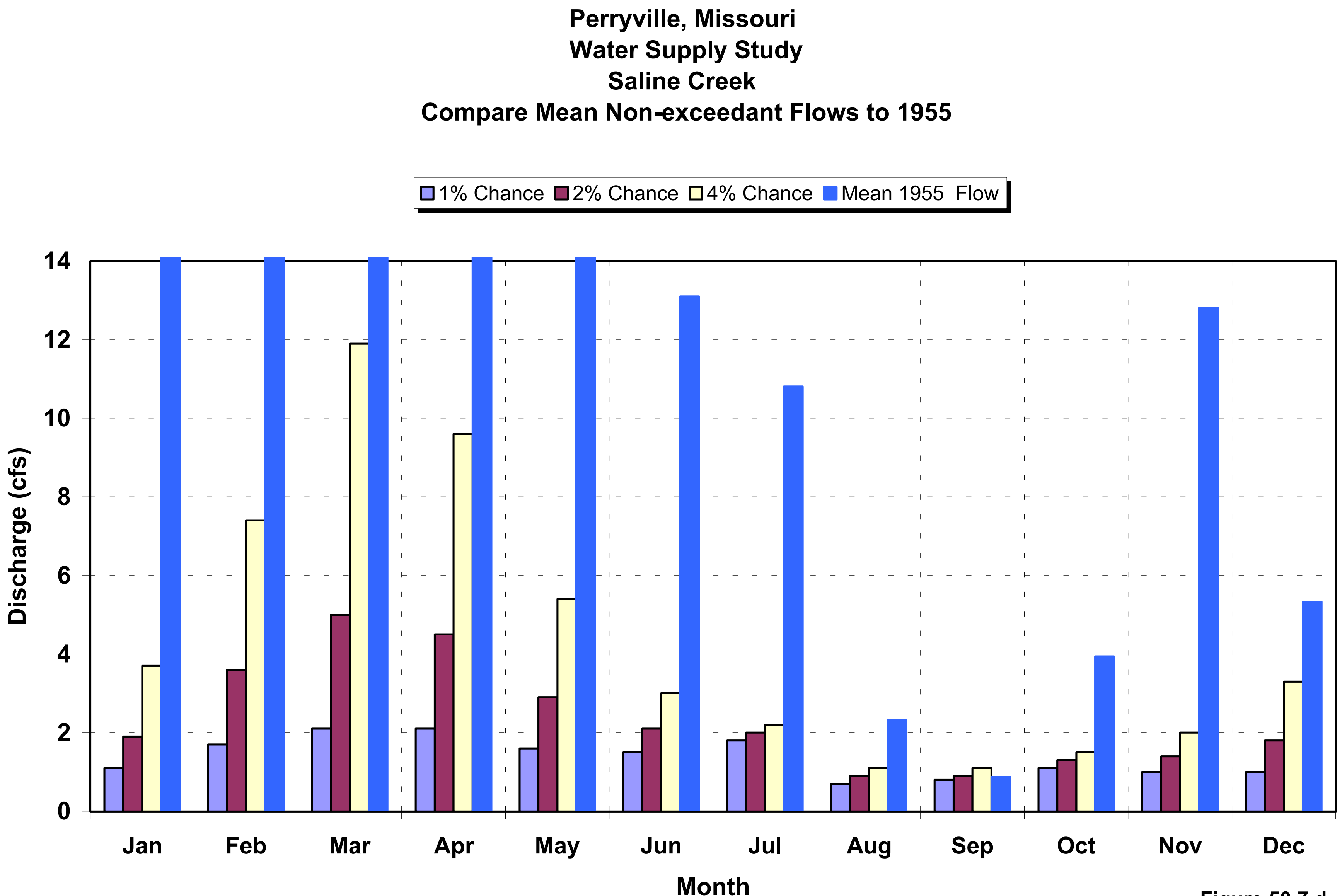

Perryville, Missouri
Water Supply Study
Saline Creek
Compare Mean Non-exceedant Flows to 1955
1% Chance
2% Chance
4% Chance
Mean 1955 Flow
Discharge (cfs)
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.7.d

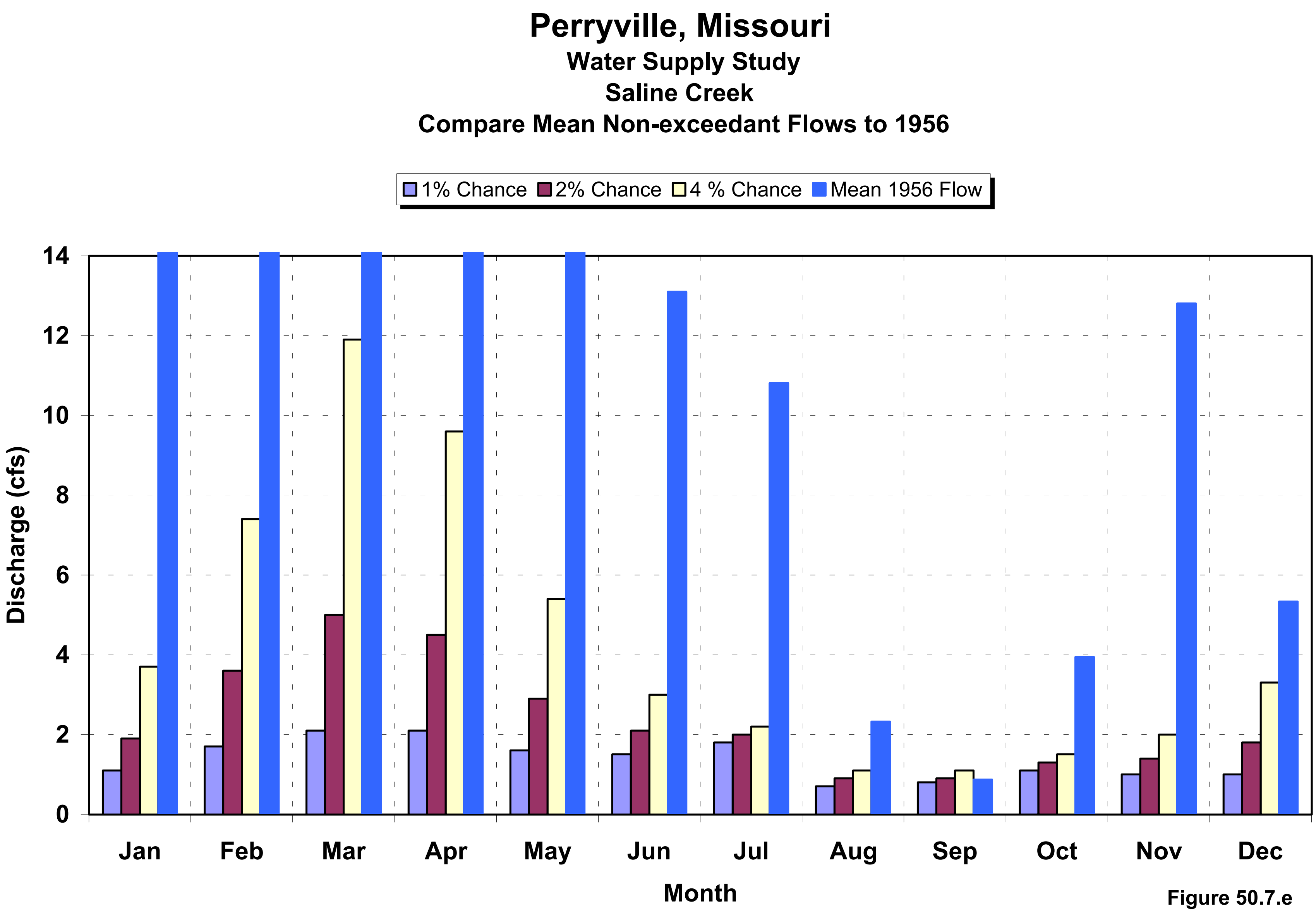

Perryville, Missouri
Water Supply Study
Saline Creek
Compare Mean Non-exceedant Flows to 1956
1% Chance
2% Chance
4 % Chance
Mean 1956 Flow
Discharge (cfs)
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.7.e

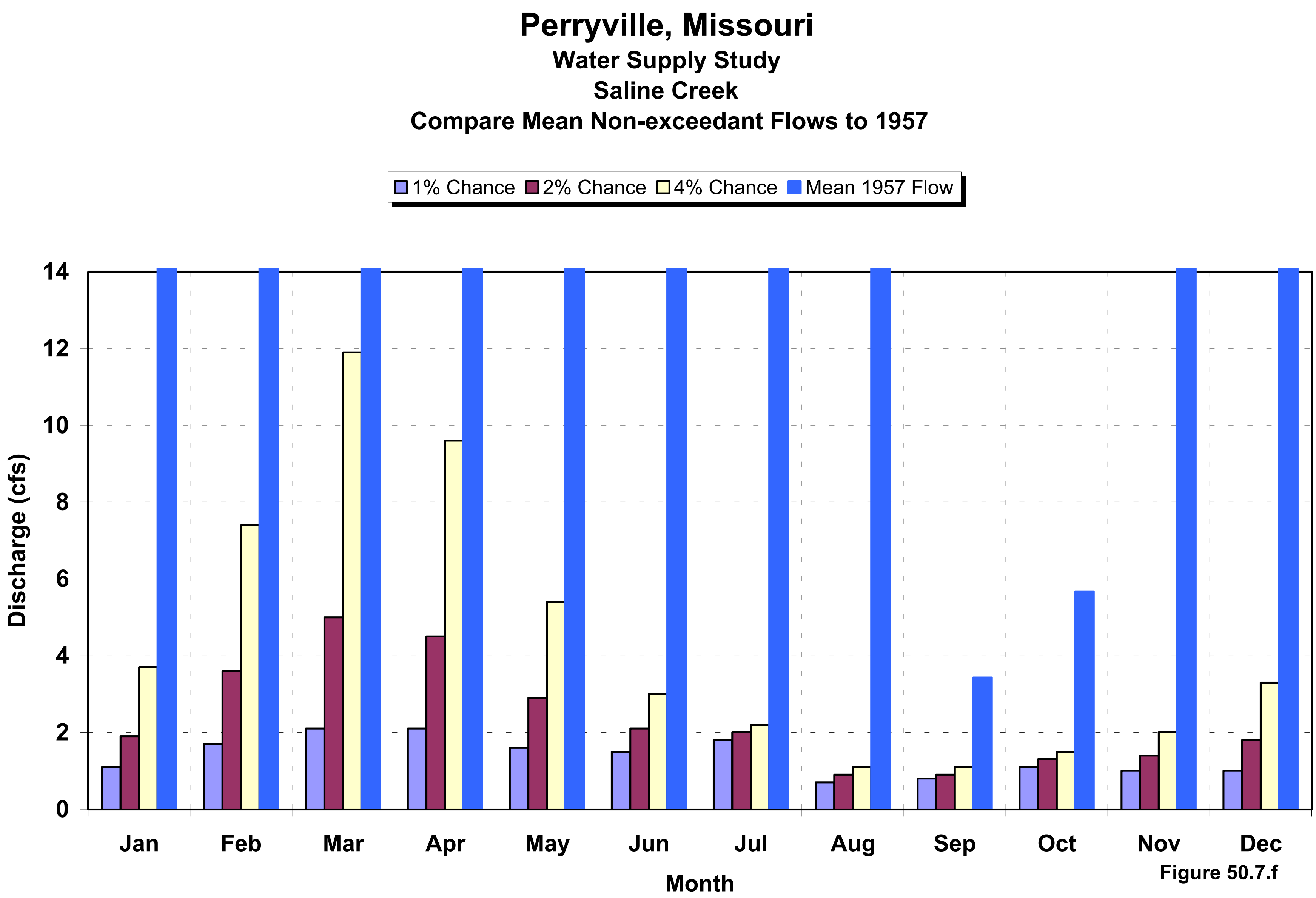

Perryville, Missouri
Water Supply Study
Saline Creek
Compare Mean Non-exceedant Flows to 1957
1% Chance
2% Chance
4% Chance
Mean 1957 Flow
Discharge (cfs)
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.7.f

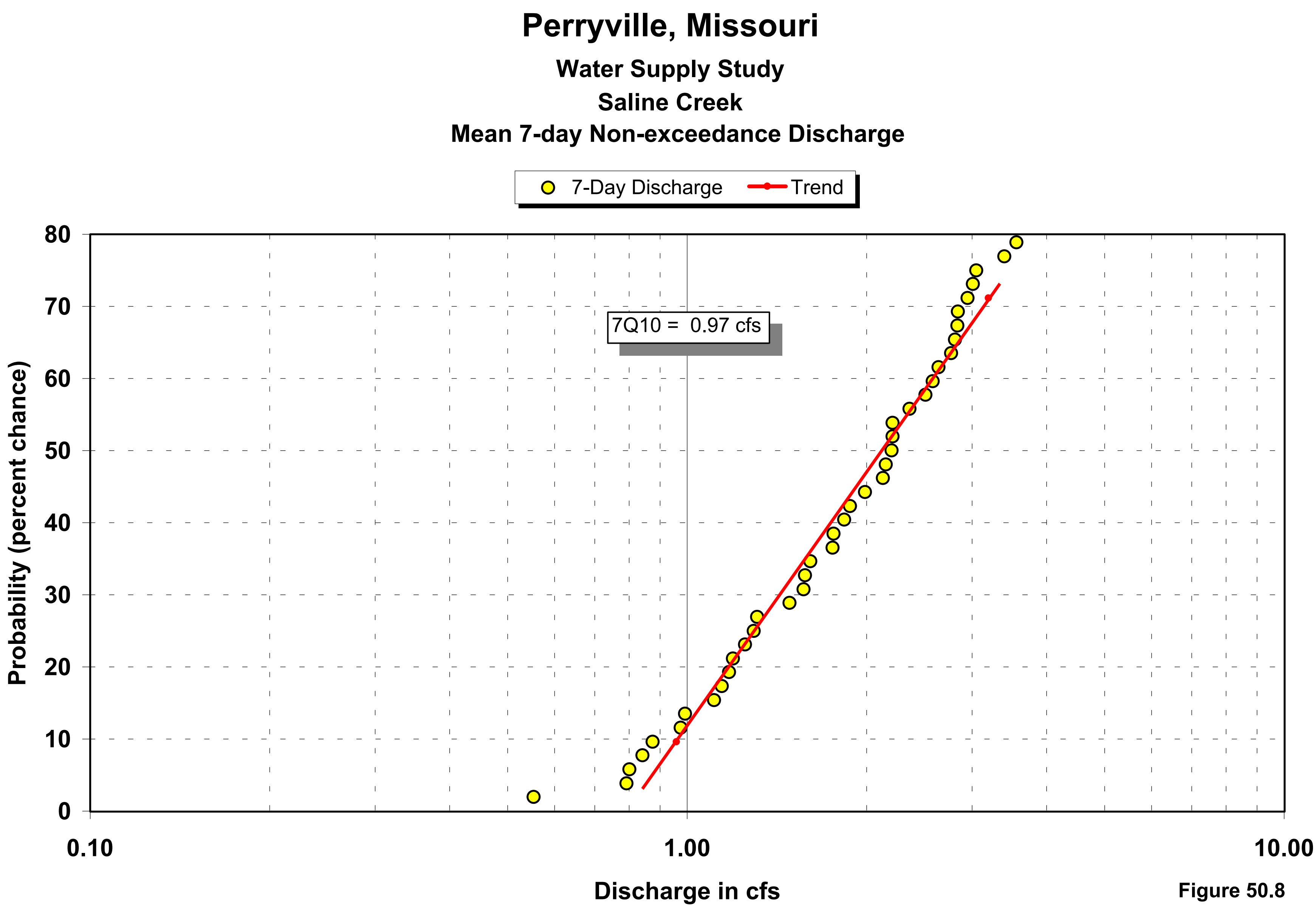

Perryville, Missouri
Water Supply Study
Saline Creek
Mean 7-day Non-exceedance Discharge
7-Day Discharge
Trend
7Q10 = 0.97 cfs
Probability (percent chance)
0
10
20
30
40
50
60
70
80
0.10
1.00
10.00
Discharge in cfs

Figure 50.8

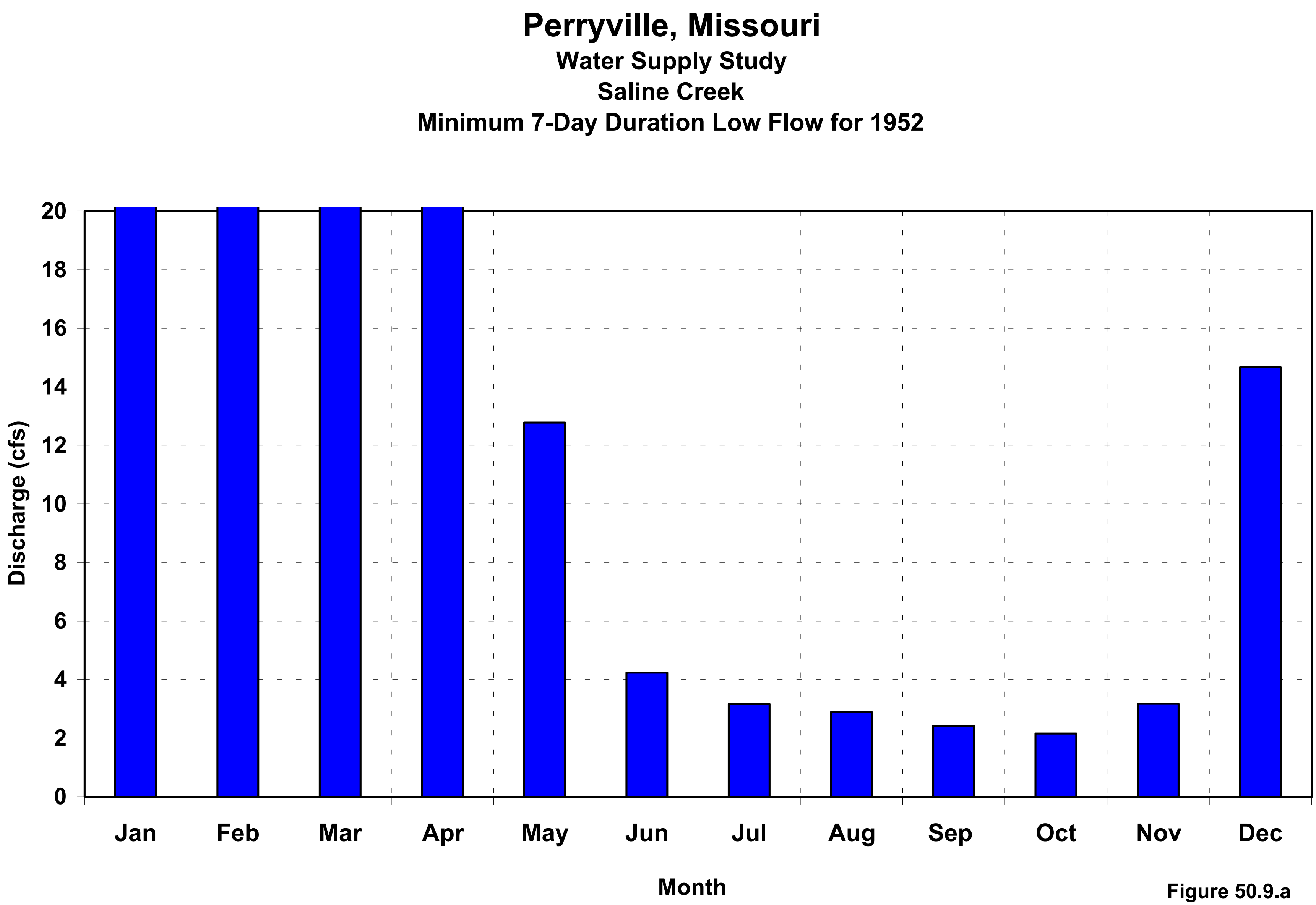

Perryville, Missouri
Water Supply Study
Saline Creek
Minimum 7-Day Duration Low Flow for 1952
Discharge (cfs)
0
2
4
6
8
10
12
14
16
18
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.9.a

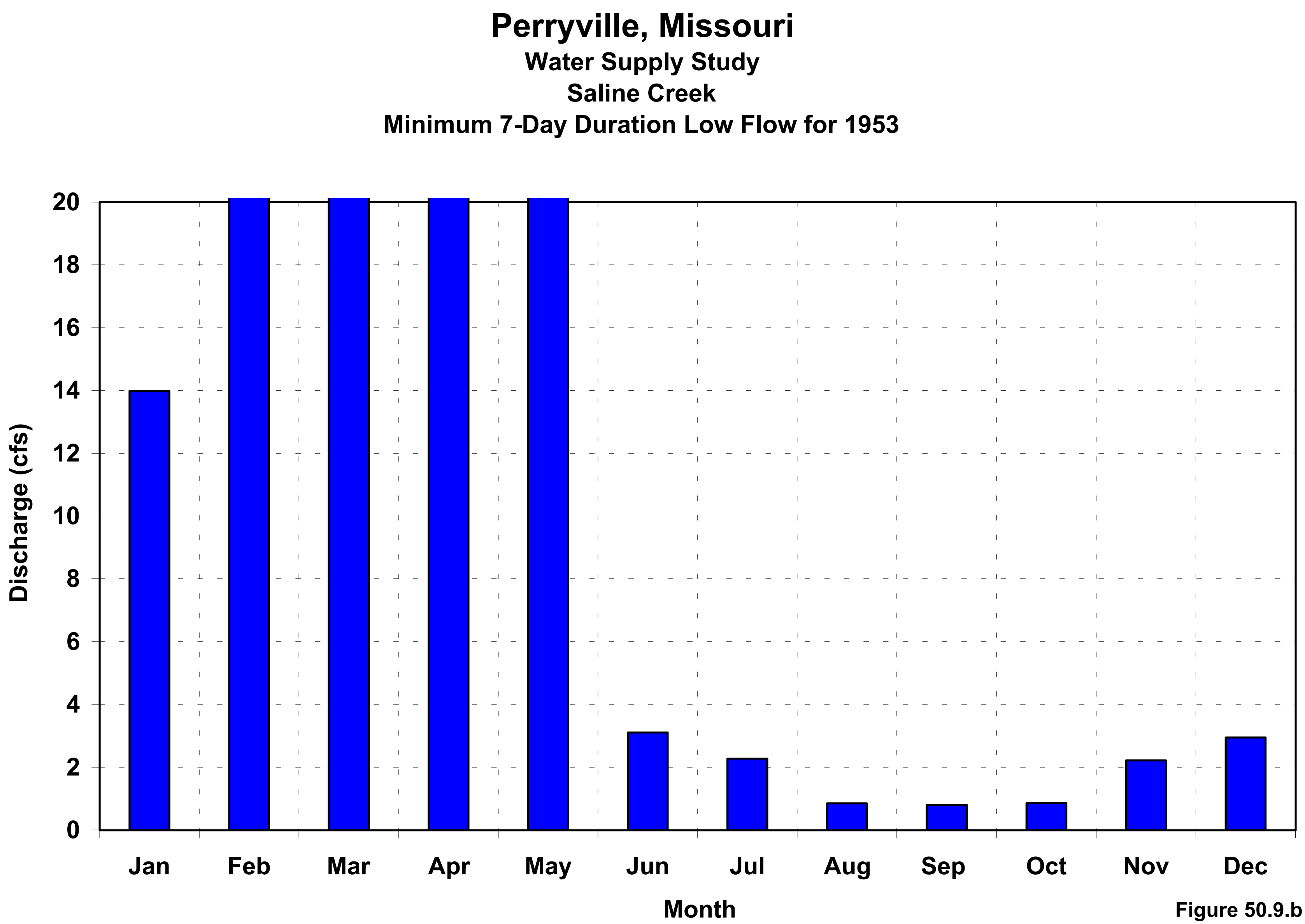

Perryville, Missouri
Water Supply Study
Saline Creek
Minimum 7-Day Duration Low Flow for 1953
Discharge (cfs)
0
2
4
6
8
10
12
14
16
18
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.9.b

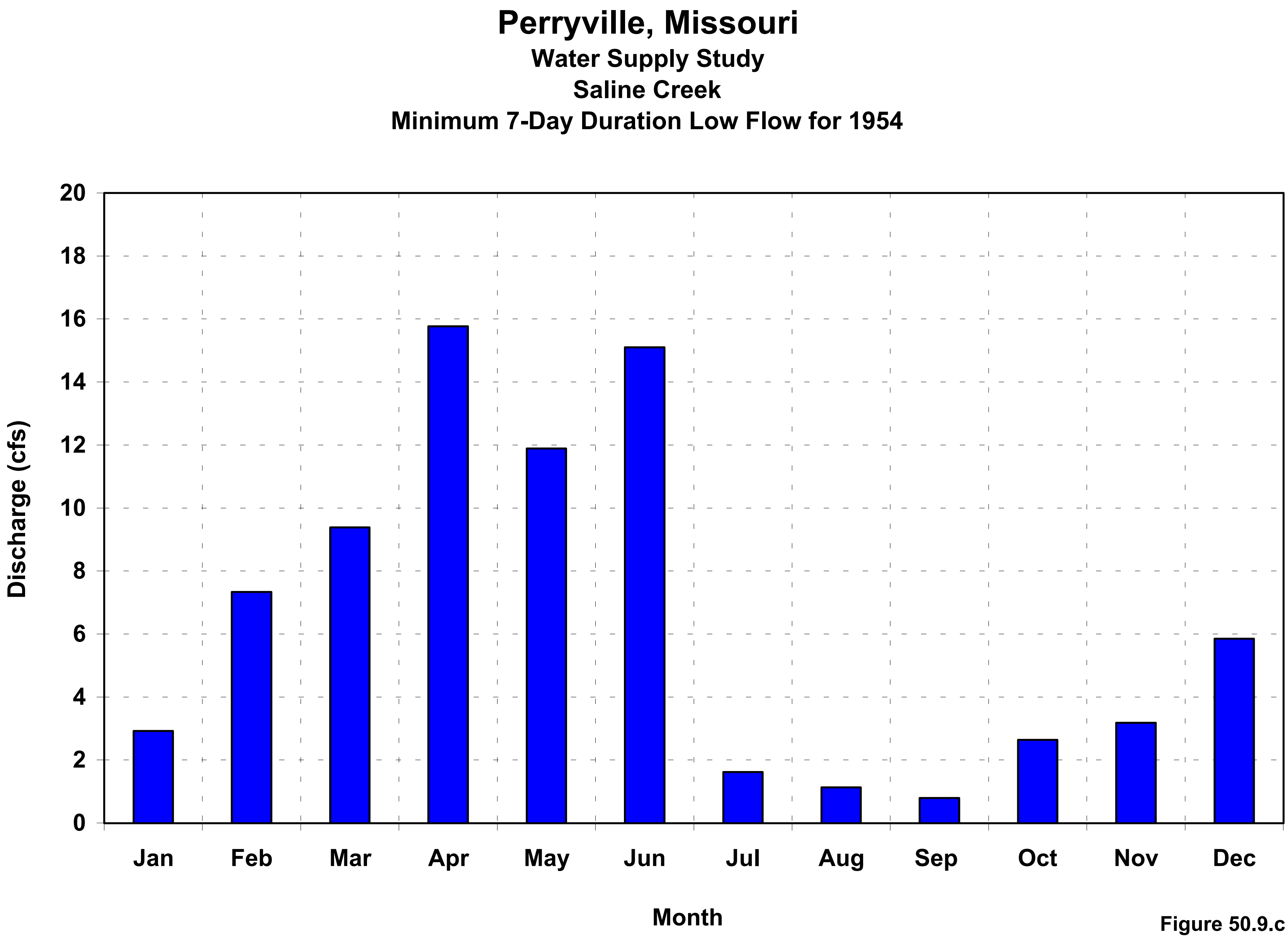

Perryville, Missouri
Water Supply Study
Saline Creek
Minimum 7-Day Duration Low Flow for 1954
Discharge (cfs)
0
2
4
6
8
10
12
14
16
18
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.9.c

Perryville, Missouri
Water Supply Study
Saline Creek
Minimum 7-Day Duration Low Flow for 1955

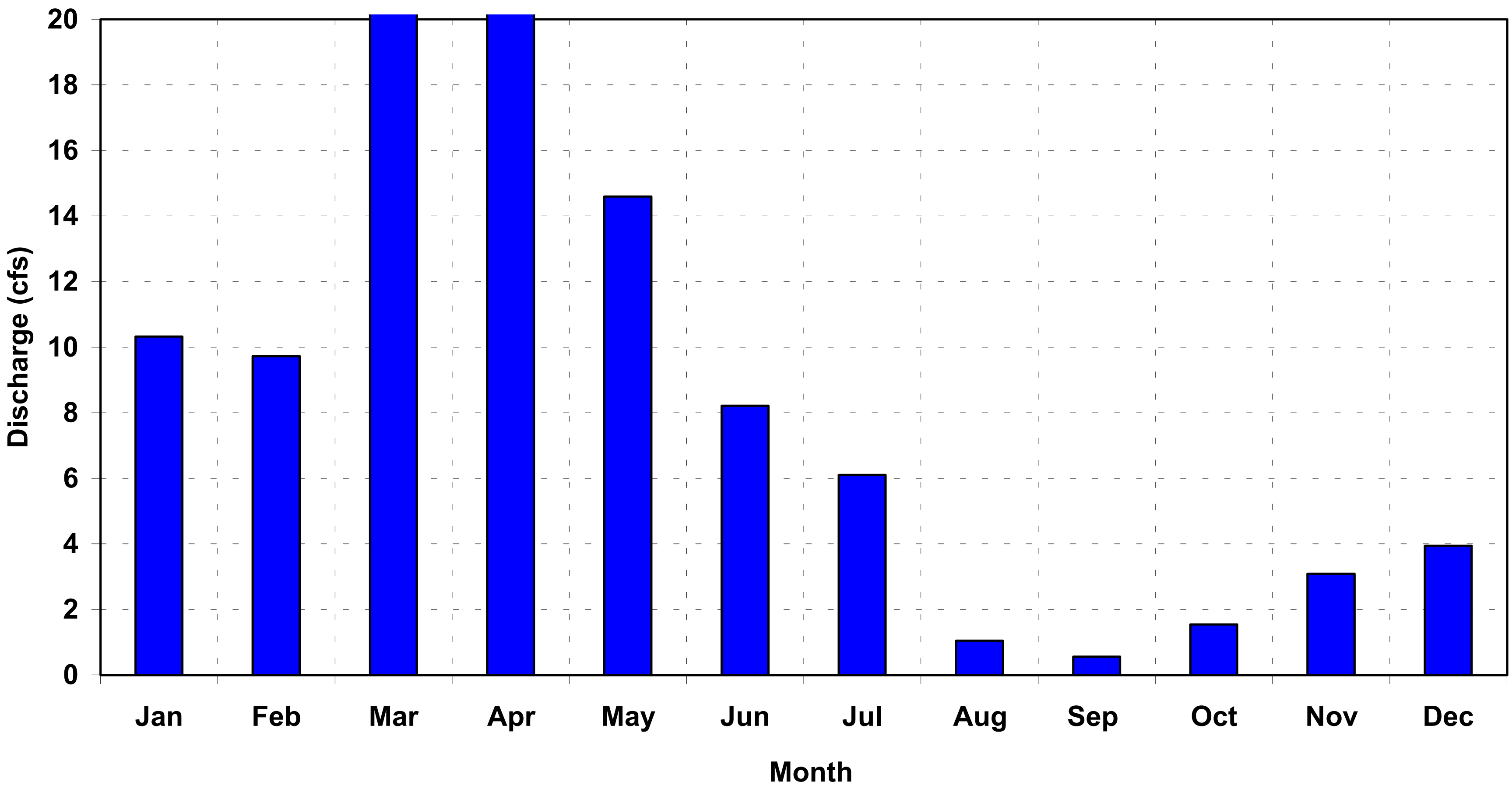


Figure 50.9.d

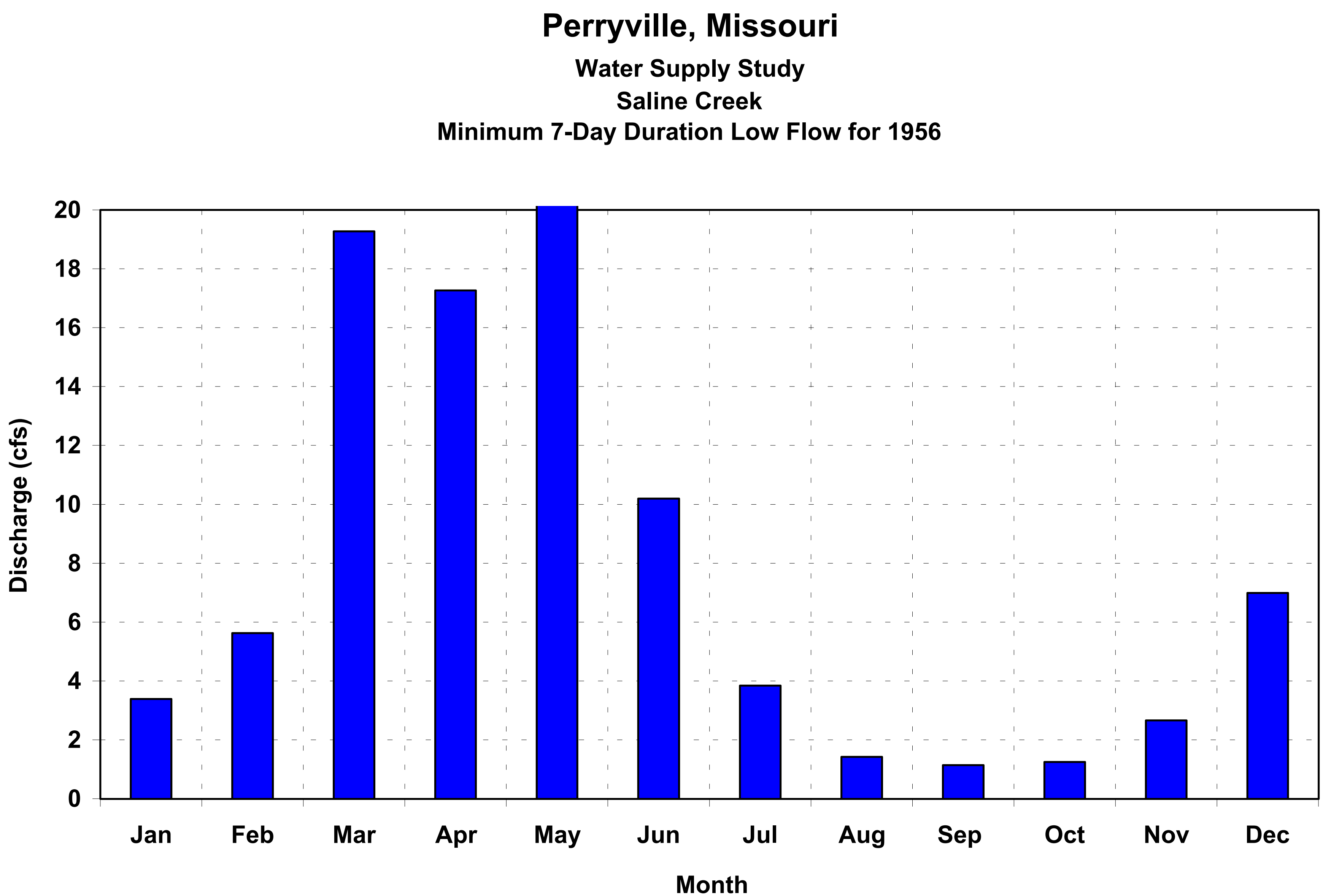

Perryville, Missouri
Water Supply Study
Saline Creek
Minimum 7-Day Duration Low Flow for 1956
Discharge (cfs)
0
2
4
6
8
10
12
14
16
18
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.9.e

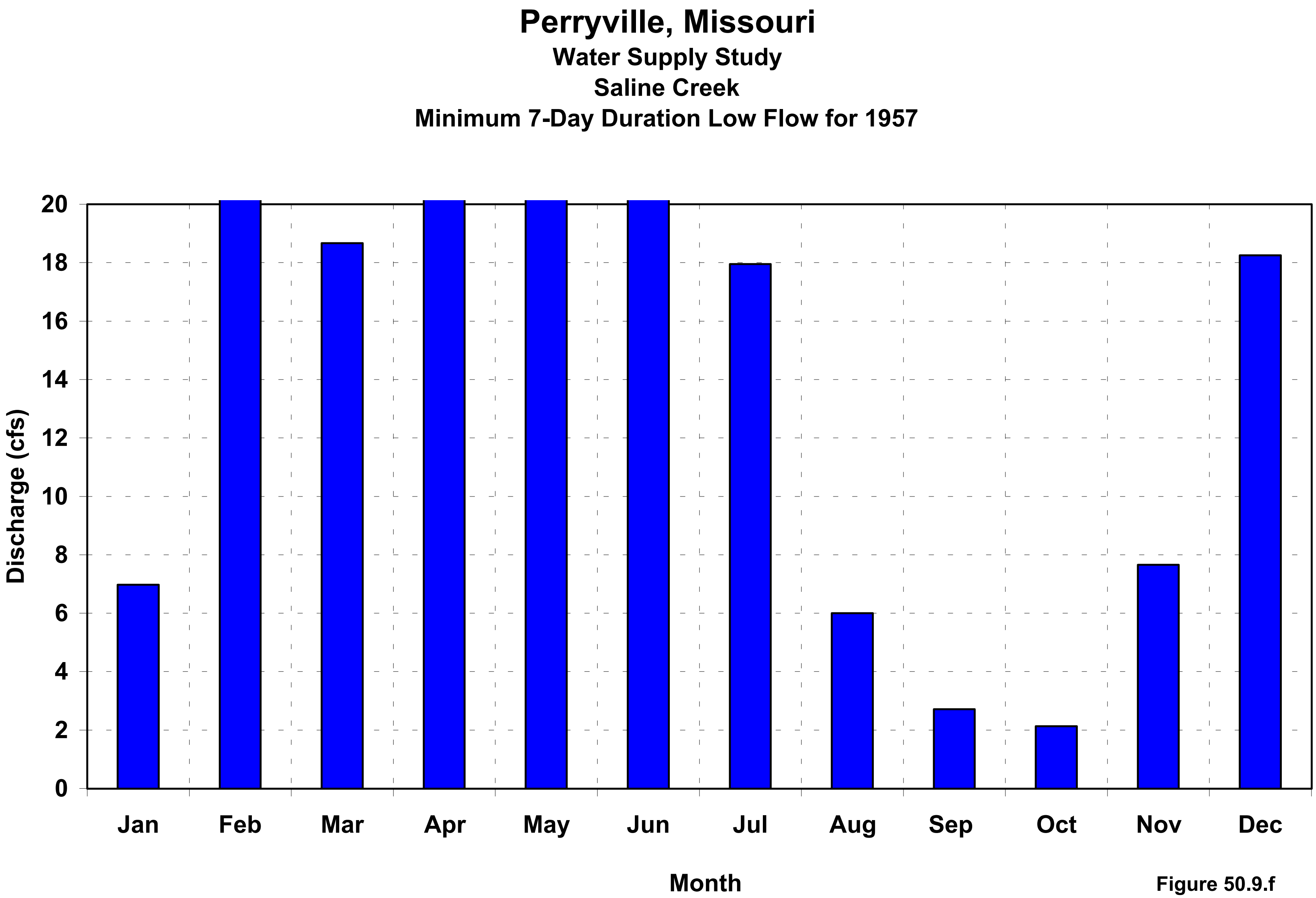
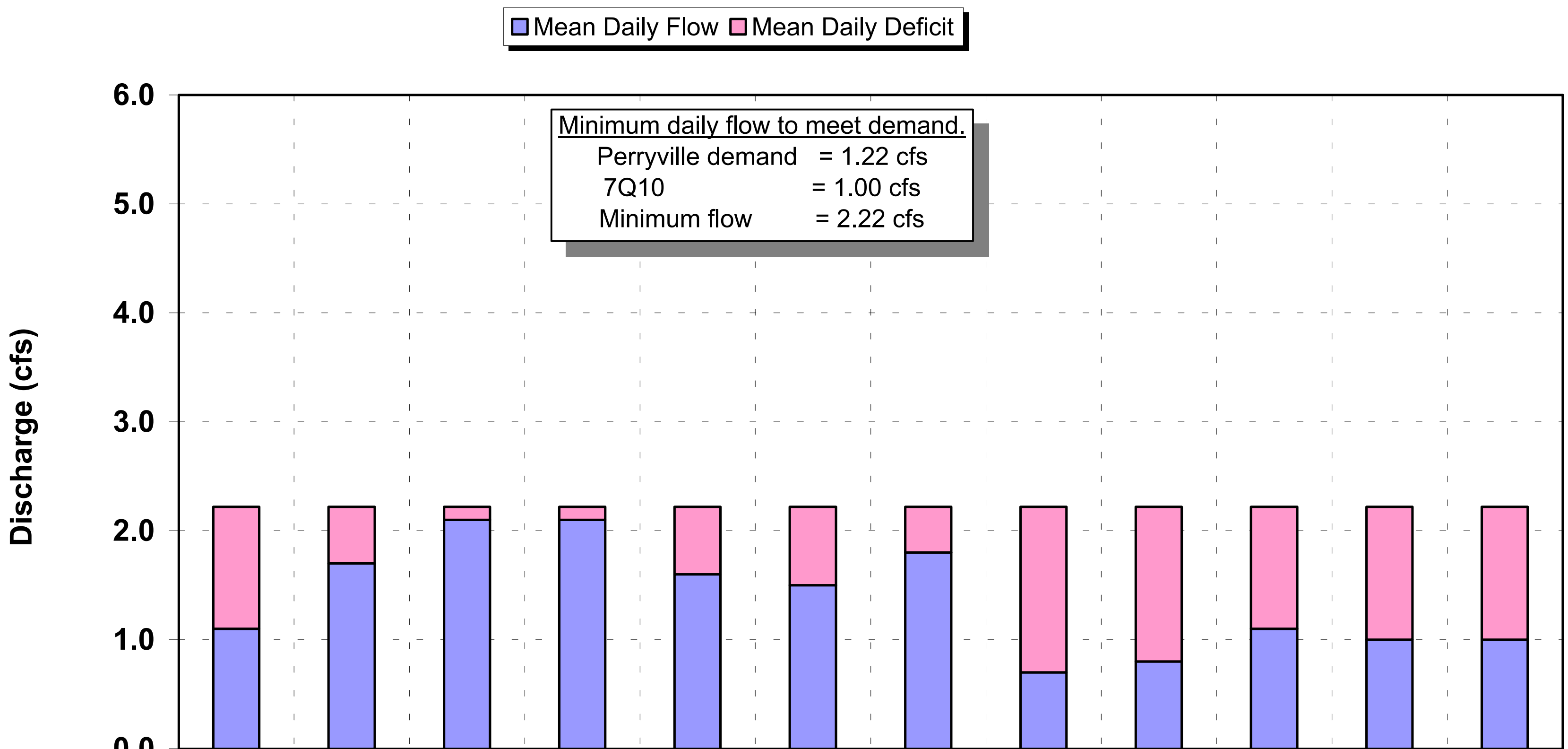

Perryville, Missouri
Water Supply Study
Saline Creek
Minimum 7-Day Duration Low Flow for 1957
Discharge (cfs)
0
2
4
6
8
10
12
14
16
18
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 50.9.f

Perryville, Missouri
Water Supply Study
Saline Creek
1% Chance Non-exceedant Flow or 1 year in 100

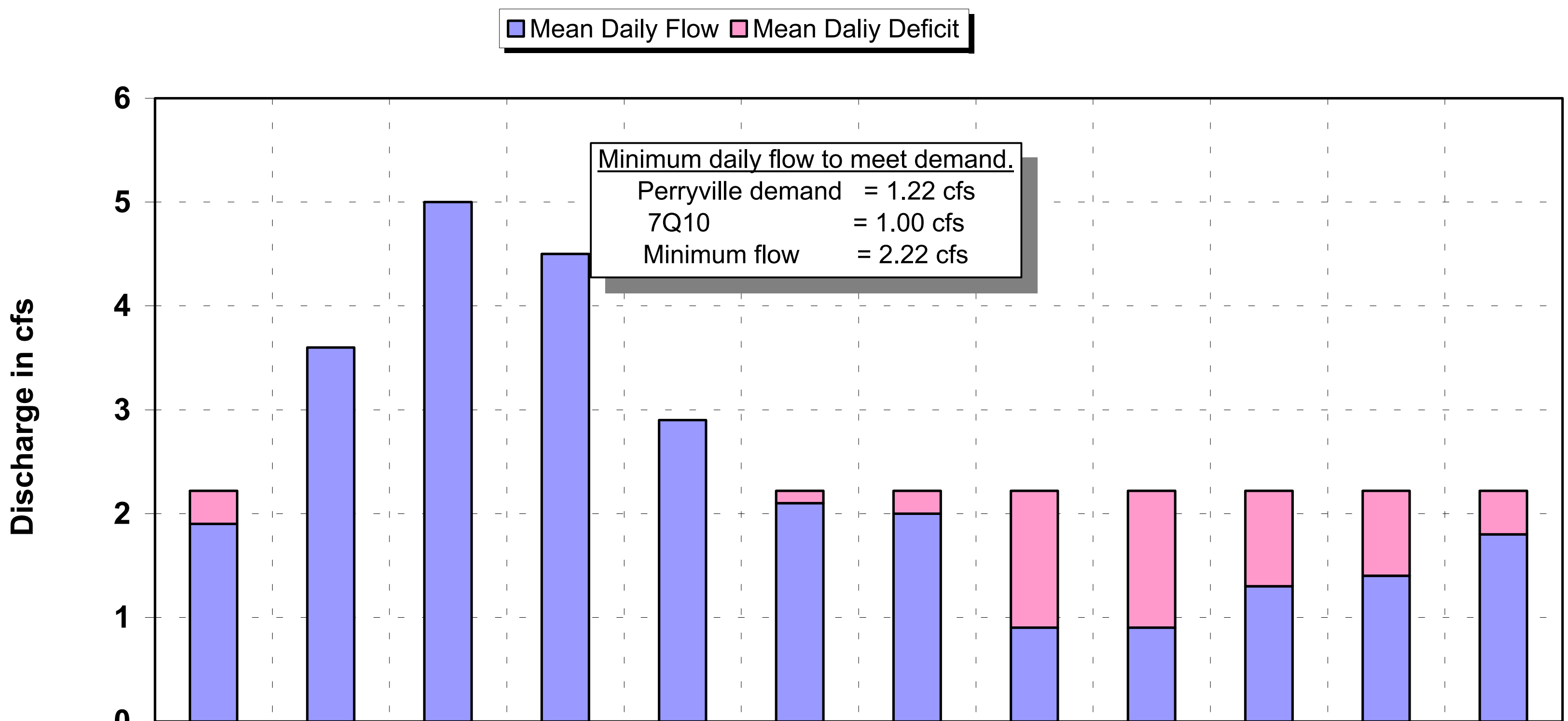


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Daily Deficit	1.12	0.52	0.12	0.12	0.62	0.72	0.42	1.52	1.42	1.12	1.22	1.22
Mean Daily Flow	1.1	1.7	2.1	2.1	1.6	1.5	1.8	0.7	0.8	1.1	1	1

Month

Figure 50.10.a

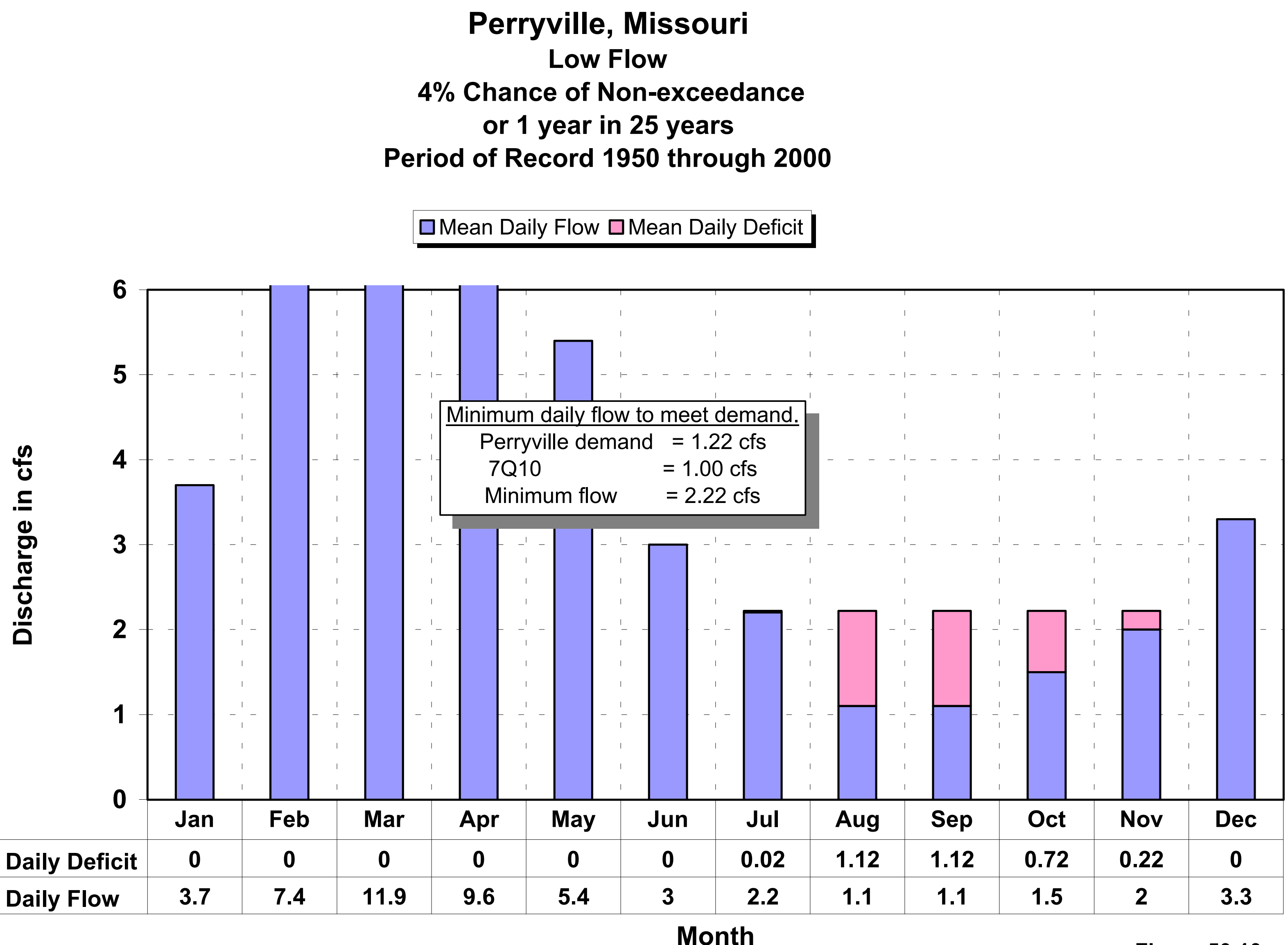
Perryville, Missouri
Water Supply Study
Saline Creek
2% Chance of Non-exceedant Flow or 1 year in 50



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Daliy Deficit	0.32	0	0	0	0	0.12	0.22	1.32	1.32	0.92	0.82	0.42
Mean Daily Flow	1.9	3.6	5	4.5	2.9	2.1	2	0.9	0.9	1.3	1.4	1.8

Month

Figure 50.10.b



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Daily Deficit	0	0	0	0	0	0	0.02	1.12	1.12	0.72	0.22	0
Mean Daily Flow	3.7	7.4	11.9	9.6	5.4	3	2.2	1.1	1.1	1.5	2	3.3

Figure 50.10.c

Perryville, Missouri
Water Supply Study
Saline Creek
Mean Discharge per Square Mile Drainage Area

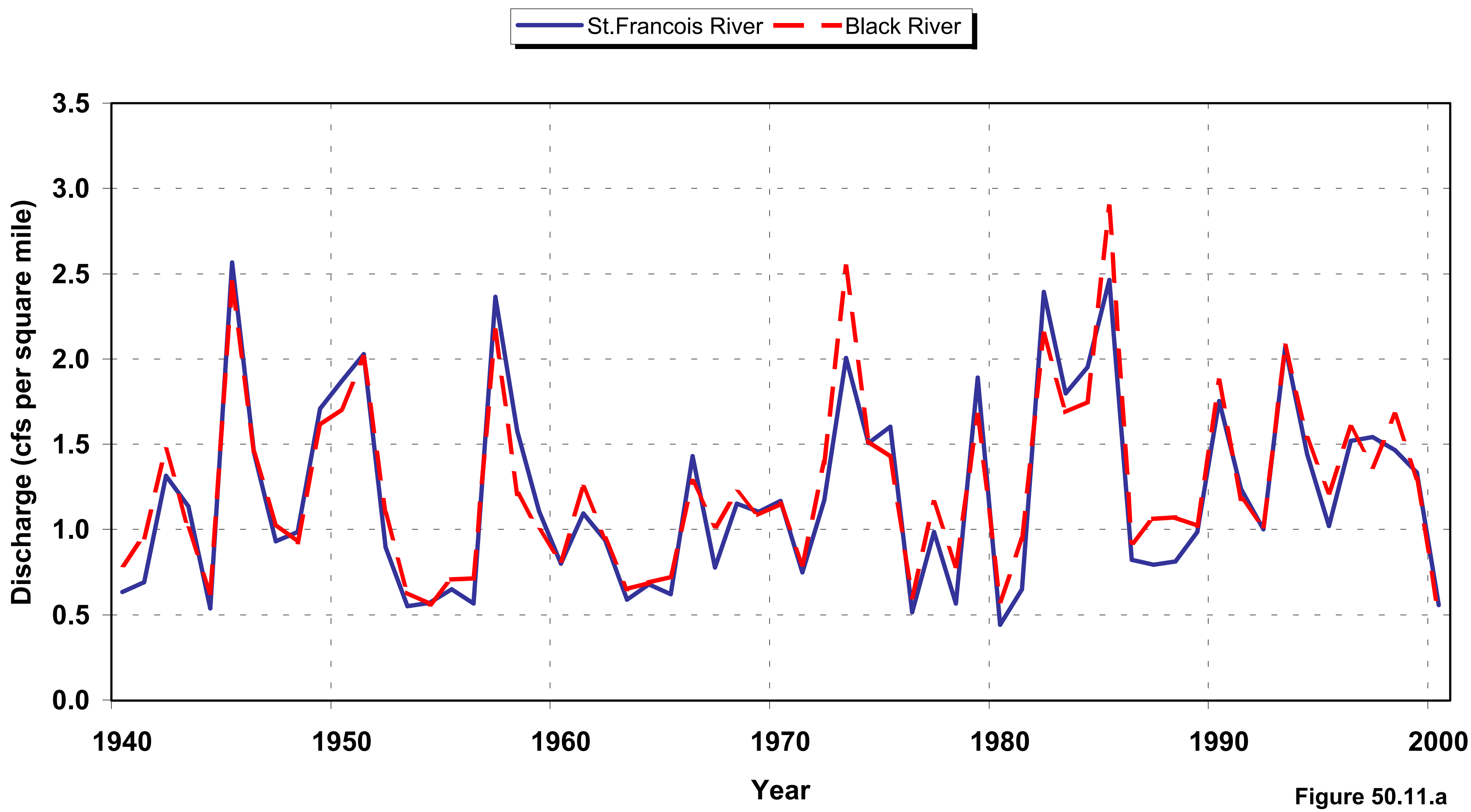


Figure 50.11.a

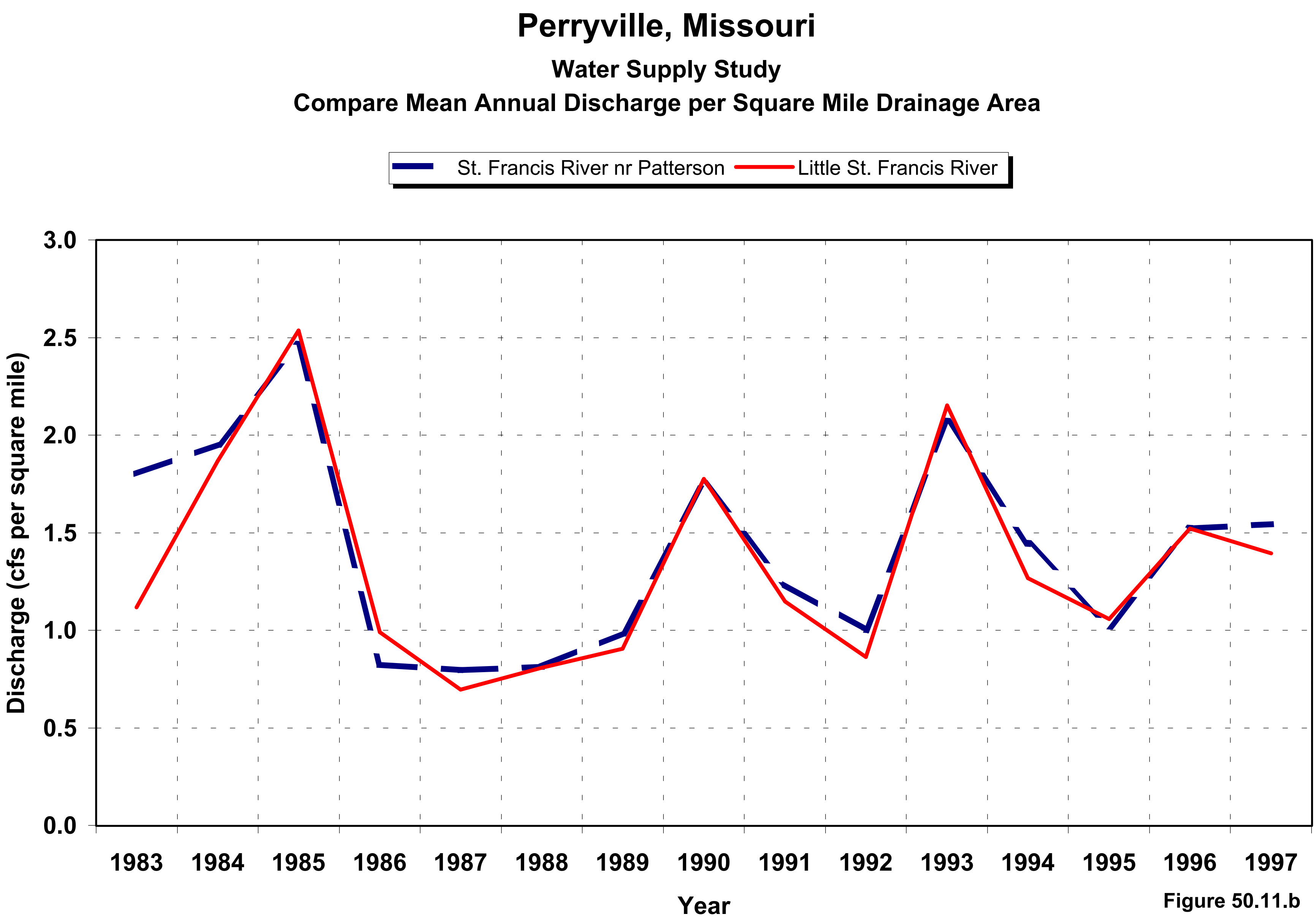


Figure 50.11.b

POPLAR BLUFF, MISSOURI
Water Supply Study
Black River

Overview:

This analysis was made to assess the availability of Poplar Bluff's water supply. Poplar Bluff gets their water supply from the Black River. In 2001 there was an average of 3.075 million gallons per day (4.76 cfs) diverted from Black River, which is fed by numerous springs throughout its drainage area and a continuous release from Clearwater Reservoir.

Poplar Bluff obtains their municipal water from the Black River. There is no off channel storage to draw upon during periods of low flow. The trend is increasing at the rate of 75,000 gallon per day. Figure 60.1 illustrates the daily water use by Poplar Bluff, in million gallons per year. During the period of 1985 through 2001 Poplar Bluff's water use has increased from 1.937 million gallons per day in 1985 to 3.075 million gallons per day in 2001. In addition, Piedmont uses water from the Black River and uses an average of 164.25 million gallons or 0.45 million gallons per day. Their intake is about one mile below Clearwater Dam. The drainage area at the intake for Poplar Bluff is 1245 square miles. There are two stream gauges on Black River, one at Poplar Bluff with a drainage area of 1245 square miles and the other at Annapolis, drainage area is 484 square miles. Upstream of Poplar Bluff is Clearwater Lake at drainage area 898 square miles. Completion of the lake was in 1948. A minimum continuous release rate from the lake of 150 cfs, the estimated base flow, is maintained at the dam. Below the dam, Piedmont and Poplar Bluff use stream flow for their municipal water supplies. Clearwater Dam was designed for flood control and has no storage for municipal supplies. In the year 2001 Poplar Bluff used 1,123 million gallons of water, or 3.075 million gallons per day.

Clearwater Reservoir is owned and operated by the Corps of Engineers and is managed for flood control. The most severe drought that has been recorded in the Black River Basin was for the period 1952 through 1956. Clearwater Lake was able to maintain normal Minimum releases during all drought periods.

Stream Flow data was obtained from USGS water supply papers. Mean daily discharges for the Black River at Poplar Bluff were used to analyze stream flow volumes and frequencies. Continuous records have been kept from 1941 through 2002. Their intake is located within the corporate limits. Statistical determinations were made using the Log Pearson type III method as described in Water Resource Council bulletin 17B.

Drought Assessment

Annual precipitation amounts for most of Missouri have been increasing during the last 50 years. This is shown in the state water plan. The study was recently made for the state by Steve Hu (former state climatologist at University of Missouri) to update climate data. Figure 60.2 illustrates the precipitation at Poplar Bluff for the period 1920 through 2001. This indicates the precipitation trend to be nearly uniform for the period of record.

Figure 60.3.a shows the annual runoff in watershed inches for the Black River at Poplar Bluff. The trend indicates an increase in total annual runoff from 13 inches to 17 inches or approximately 31 percent from 1941 to year 2000. Figure 60.3.b shows the runoff in terms of mean annual cubic feet per second.

Base flow separation was made using the USGS computer program, HYSEP. HYSEP separates the base flow from the total hydrograph. This analysis was made to estimate sustained flow, to establish availability of continuous stream flow. To establish minimum discharges at Poplar Bluff it was necessary to adjust for the intervening area below Clearwater Dam. Figure 60.4.a is the base flow index which is the ratio of base flow to total

stream flow. This chart shows the annual base flow index is nearly constant at approximately 68 percent of the total flow for the period 1951 through 2000. Figure 60.4.b displays the base flow in terms of cfs. Each year fluctuates between a mean annual low of 530 cfs in 1954 to a high of 1600 cfs in 1985. Figure 60.4.c is the total stream flow before separating the base flow. Corresponding discharges are 770 cfs and 3100 cfs.

Mean annual 7-day non-exceedance (low flows) for 1941 through 2000 were calculated and are shown in figure 60.5. The lowest mean 7-day discharge occurred in 1944 with a value of 243 cfs for the year. All other months provided discharges sufficient for diverting water for municipal uses.

Monthly non-exceedance probabilities (low flows) for 1% chance of occurrence (1 time in 100 years), 2% chance (1 time in 50 years) and 4% chance (1 time in 25 years) were established from stream flow data for the years 1950 through 2000. Figure 60.6 displays these results. For this report, all statistical determinations were made using the Log Pearson Type III method as described in Water Resource Council bulletin 17B.

Stream gauge records on Black River at Poplar Bluff show the drought of record to be in the 1950's. The following figures 60.7.a, 60.7.b, 60.7.c, and 60.7.d compare the 1%, 2% and 4% chance mean monthly non-excedence flows (low flow) to measured flows for 1953, 1954, 1955 and 1956. All frequencies exceeded the adjusted 7Q10 frequency discharges at Poplar Bluff. In 1953, October had the lowest mean discharge of 268 cfs, which exceeded the 7Q10 discharge by 52 cfs. Low flows for 1954, 1955 and 1956 exceeded 7Q10 frequency by 84, 60 and 43 cfs respectively.

To assure that water quality standards are met most of the time, the mixing zone flow is based on the seven-day average low flow that has a recurrence interval of once in 10 years (7Q10). To determine the rate of flow needed to meet in-stream flow requirements, the 7Q10 was determined using the period of record, 1950 through 2000. Figure 60.8 shows the results of the frequency analysis to be 216 cfs. For purposes of diverting water from Black River, discharge should exceed 216 cfs. Clearwater Reservoir is located upstream of Poplar Bluff on Black River, as a result is was necessary to calculate the 7Q10 value for the area downstream of the Dam and add the minimum release rate of 150 cfs.

Additional comparisons for the 1950's drought were made using the mean 7-day low flow for examining a shorter duration. These comparisons are shown in figures 60.9.a, 60.9.b, 60.9.c and 60.9.d. These figures show the critical months for each year. In the 4-year period of 1953 through 1956 there were no months that had mean seven-day flows below 7Q10 discharge of 243 cfs.

Because all mean monthly flows exceed the 7Q10 discharge for in-stream flow needs plus withdrawal rates by the city, it is not necessary to show monthly shortages of water for Poplar Bluff. Any deficits that may occur would have a very short duration.

Clearwater Lake is a Corps of Engineers project and was constructed in 1948 to provide flood control for the downstream drainage districts. Water supply was not included in the design of this lake. During planning, it was determined that base flow at the dam site was 150 cfs. The operating plan for the lake requires a minimum of 150-cfs continuous release. The water control plan requires alerting the residents of Poplar Bluff if the stage drops below 0.3 feet. To date this has never happened and is not likely to occur. During the 1950's, the drought of record occurred from 1952 through 1956, release of 150 cfs from Clearwater Lake was maintained through the drought. There are several springs between the lake and Poplar Bluff that have continuous flow**.** Figure 60.11 shows the storage in Clearwater Reservoir from its closure to year 2000.

Special analysis considerations

Adjustment for Base Flow

Clearwater Reservoir controls all storm runoff from its drainage area of 898 square miles and releases the runoff at a minimum rate of 150 cubic feet per second. When droughts occur, low flows will be affected by releases from Clearwater to a greater extent than high flows. Therefore it is necessary to make adjustments to account for controlled and uncontrolled drainage area contribution to base flow. The total drainage area at Poplar Bluff is 1245 square miles. The uncontrolled area is 347 square miles. By determining the base flow for the uncontrolled area and adding the minimum release of 150 cubic feet per second from the reservoir we were able to determine the expected base flow for dry periods. Base flow separation was made using the USGS computer program, HYSEP. HYSEP separates the base flow hydrograph from the total hydrograph. This analysis was made to estimate sustained flow while meeting water supply needs during a drought.

To make the base flow analysis it was necessary to adjust the flow at Poplar Bluff for the uncontrolled area and add release from Clearwater Reservoir. A correlation between base flow and also total flow at Annapolis and Poplar Bluff gauges for the period of 1940 through 1948 was evaluated because they were both uncontrolled at that time. The gates on Clearwater Reservoir were closed in 1948. Figure 60.12.a is the base flow correlation and figure 60.12.b is the total flow correlation. Following are the steps to determine minimum base flow index.

Step 1. Determine base flow and total stream flow for the Annapolis and Poplar Bluff Gauges for years 1940 through 1948 using “HYSEP”.

Step 2. Plot the annual total flow and annual base flow discharges to determine the relationship of the two gauges. The resulting equations are:
Base Flow at Poplar Bluff = 2.4858 x flow at Annapolis – 5.8173 (Figure 60.12.a).
Total Flow at Poplar Bluff = 2.066 x flow at Annapolis + 55.909 (Figure 60.12.b).

Step 3. Use the above equations to determine the mean annual base flow and total flow at Poplar Bluff for the intervening drainage area between the lake and Poplar Bluff for the period 1950 through 2000.

Step 4. Add the minimum release of 150 cfs from Clearwater Reservoir to each yearly mean discharge value from step 3.

Step 5. Plot adjusted mean annual base flow in cfs vs. year. (Figure 60.4.b).

Step 6. Plot adjusted mean total annual flow in cfs vs. year. (Figure 60.4.c).

Step 7. Plot ratio of base flow to total flow for the base flow index. (Figure 60.4.a)

Adjustment for Water Quality Standard

To determine the rate of flow needed to maintain in-stream flow, the 7Q10 low flow was determined using the period of record, 1950 through 2000. The 7Q10 discharge is used to establish standards for water quality issues. Figure 60.8 shows the plot of the values for a frequency analysis. The 7Q10 analysis was determined to be 66 cfs for the intervening area below the Clearwater dam. 150 cfs was added for the minimum continuous release from Clearwater Lake and the minimum value for 7Q10 flow is 216 cfs.

Steps taken to make the adjustment for effects of Clearwater Reservoir on the minimum in-stream flow needs are:

Step 1 Determine frequency of 7-day duration mean flow for Annapolis and Poplar Bluff Gauges for years 1940 through 1948, which is the period when data was available for both gauges and before Clearwater Reservoir was constructed. Determine frequency for discharges at Annapolis and Poplar Bluff gauges for that time period.

Step 2 Convert the 7-day duration discharges in step 1 to a per square mile of drainage area for each gauge.

Step 3 Plot data in step 2, Poplar Bluff data vs. Annapolis data for 1940 through 1948, as shown in figure 60.12.c.

Step 4 Determine equation for relationship between the two gauges from step 3. The following equation for the 7Q10 low flow discharge was determined to be:

7-day duration low flow frequency =
1.6982 X (Discharge at Annapolis gauge per square mile)^2 +
0.5885* (Discharge at Annapolis gauge per square mile) + 0.597.

Step 5 Run duration frequency analysis, using Durfrek computer program, Black River at Annapolis stream gauge data for years 1950 through 2000 for 7-day duration.

Step 6 Convert results in step 5 to a per square mile basis by dividing by drainage area at the Annapolis gauge.

Step 7 Multiply results in step 6 by the 346 square miles drainage area below Clearwater Reservoir.

Step 8 Add 150 cfs to each frequency value in step 7 to account for minimum release from Clearwater Reservoir.

Step 9 Plot results of 7Q10 discharge in step 7 for the intervening area. Also plot step 8 results for the total 7-day 10-year frequency total discharge with constant release from Clearwater Reservoir.

Step 10 Minimum 7-day 10-year frequency discharge was determined to be 66 cfs from the intervening area plus 150 cfs constant release from Clearwater Reservoir established flow requirement for in-stream needs of 216 cfs.

Poplar Bluff, Missouri

Water Supply Study
Water Use

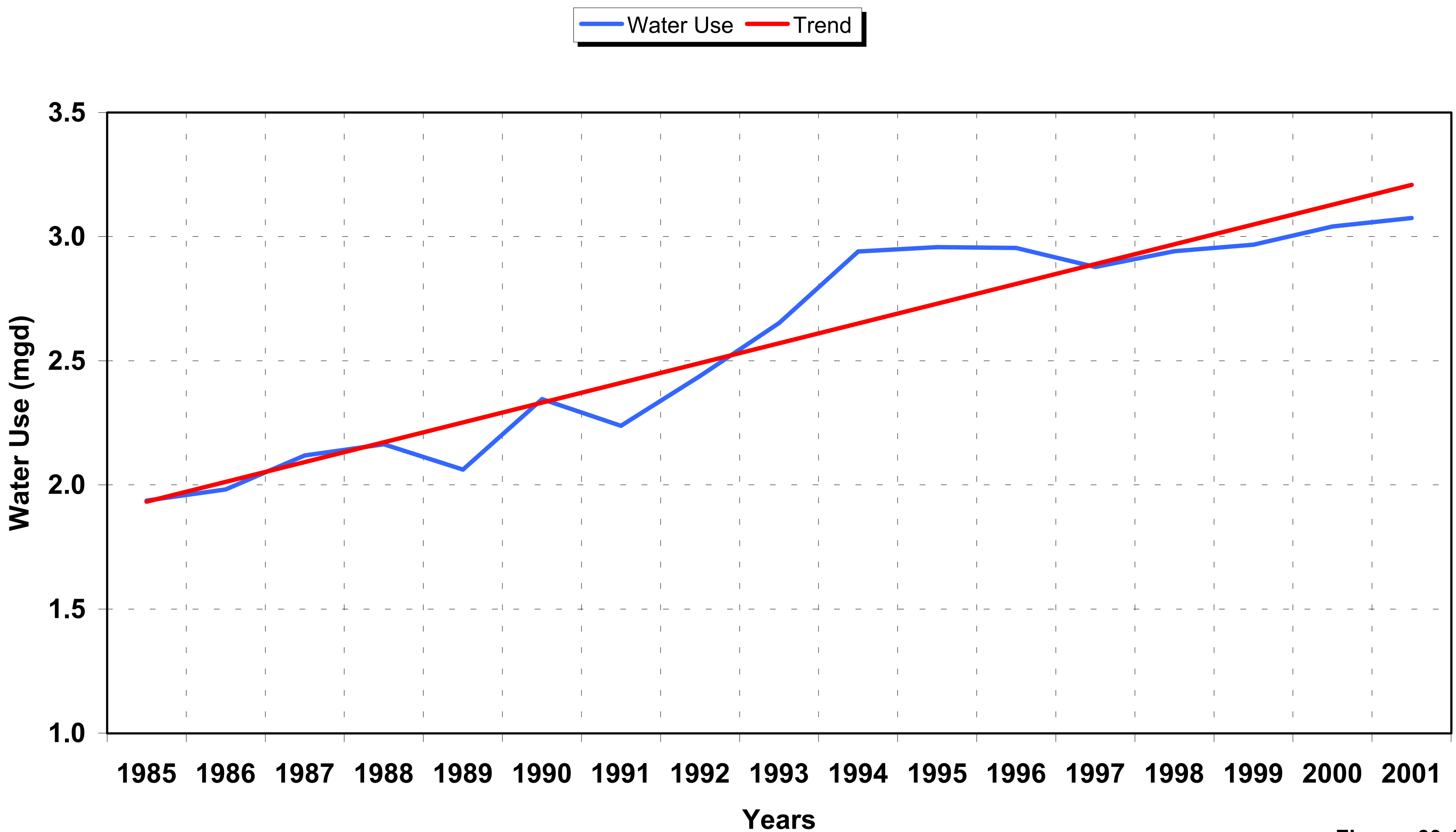


Figure 60.1

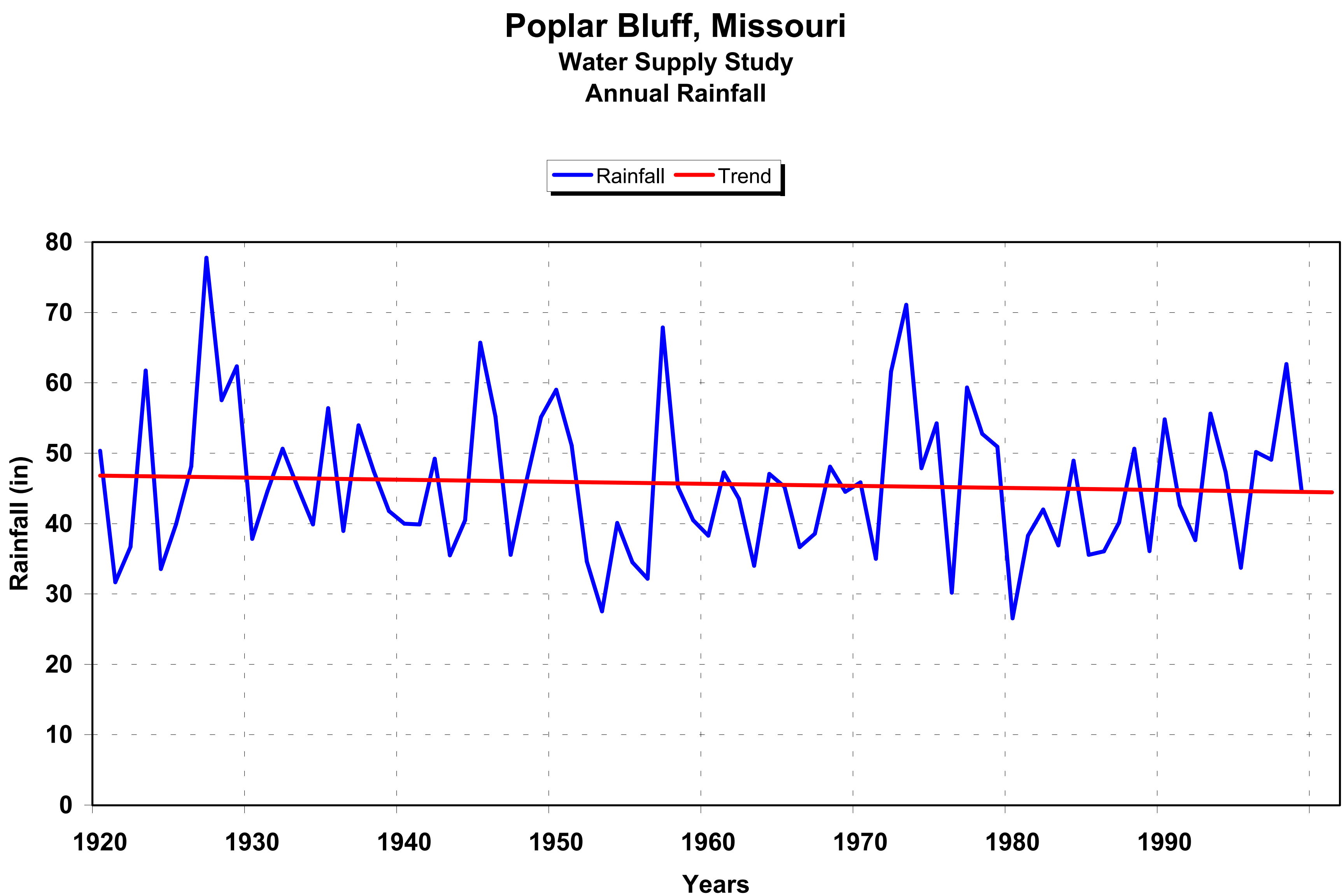

Poplar Bluff, Missouri
Water Supply Study
Annual Rainfall
Rainfall
Trend
80
70
60
50
40
30
20
10
0
Rainfall (in)
1920
1930
1940
1950
1960
1970
1980
1990
Years

Figure 60.2

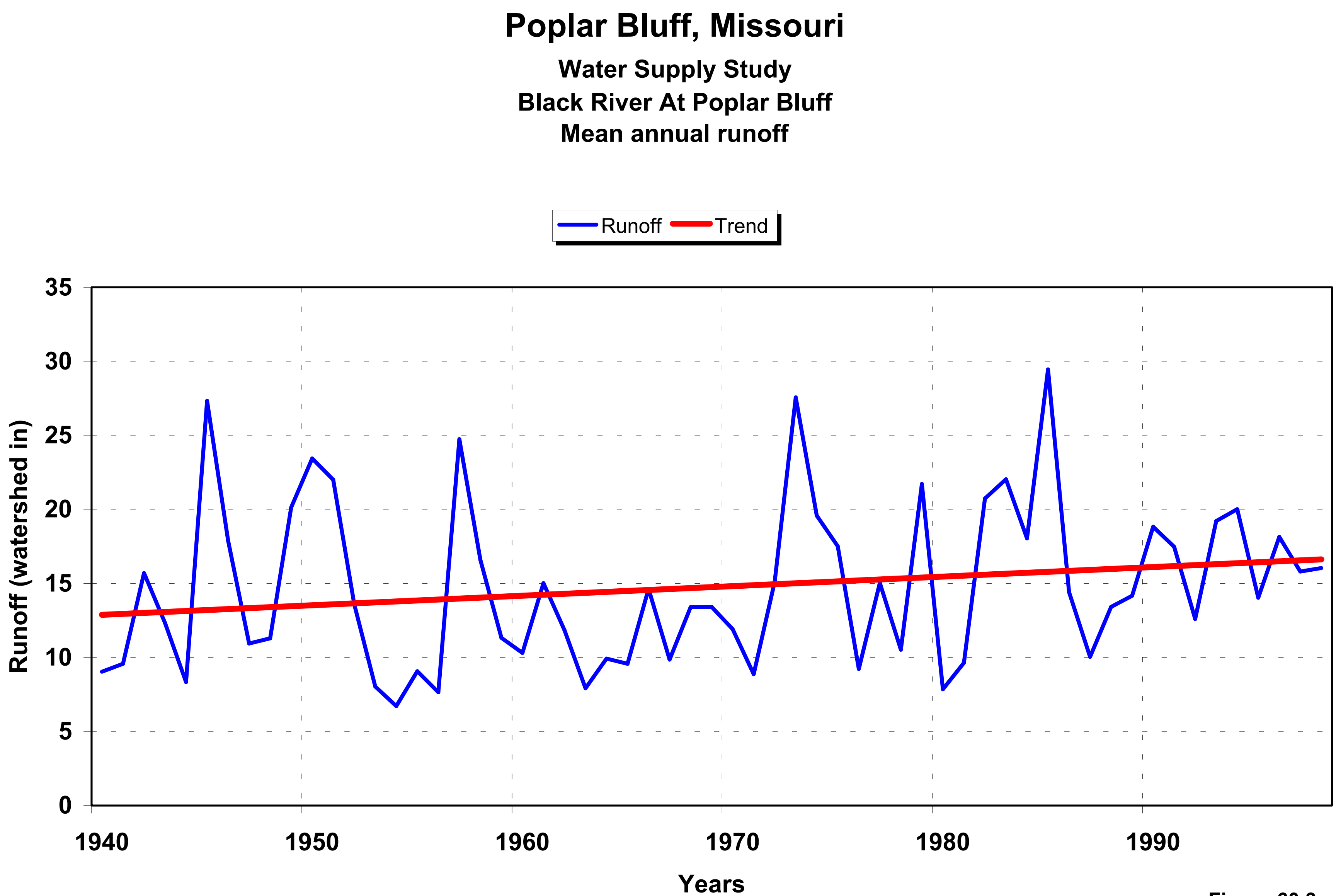

Poplar Bluff, Missouri
Water Supply Study
Black River At Poplar Bluff
Mean annual runoff
Runoff
Trend
Runoff (watershed in)
0
5
10
15
20
25
30
35
1940
1950
1960
1970
1980
1990
Years

Figure 60.3.a

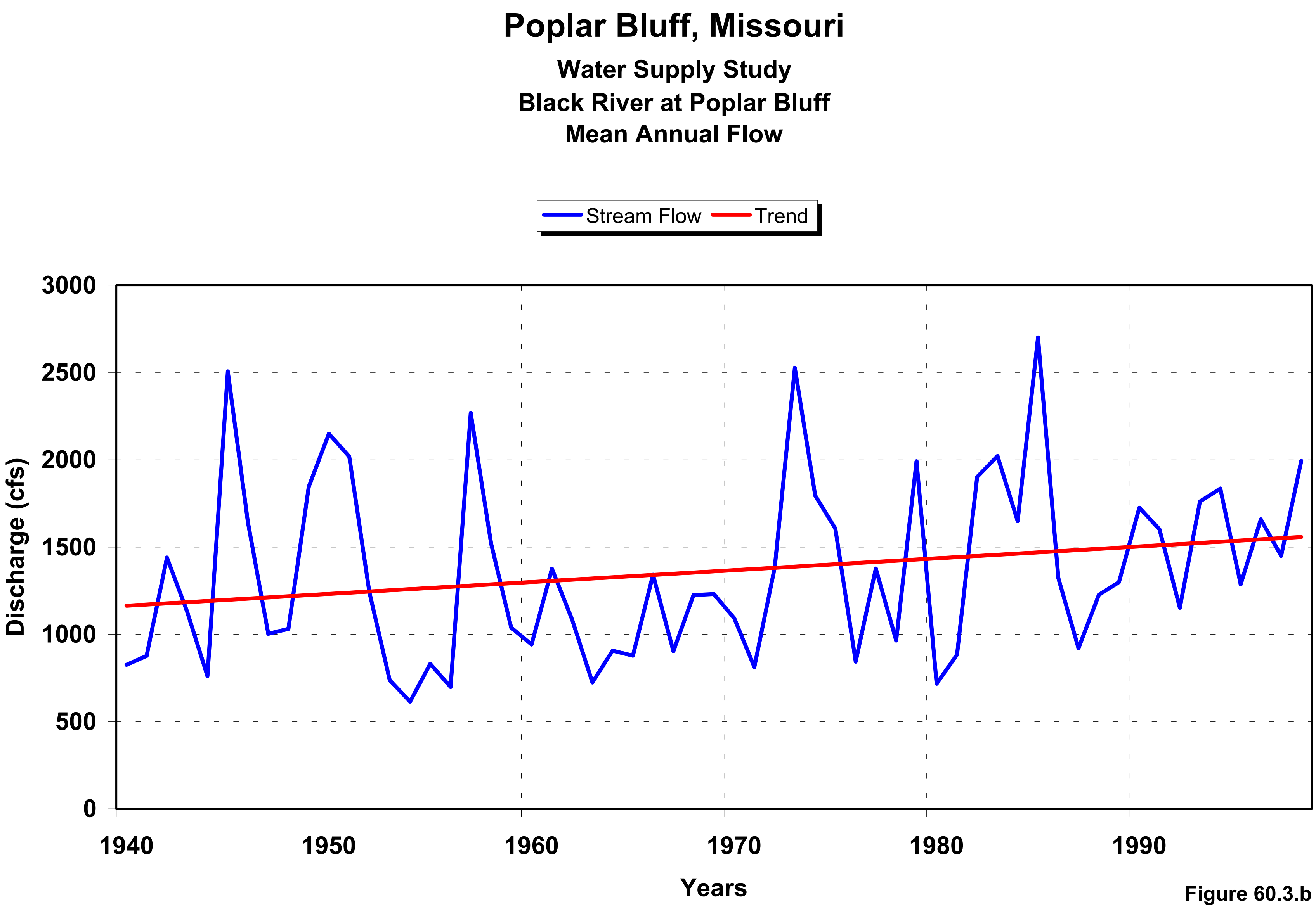

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
Mean Annual Flow
Stream Flow
Trend
3000
2500
2000
1500
1000
500
0
Discharge (cfs)
1940
1950
1960
1970
1980
1990
Years

Figure 60.3.b

Poplar Bluff, Missouri

Water Supply Study
Black River at Poplar Bluff
Base Flow Index

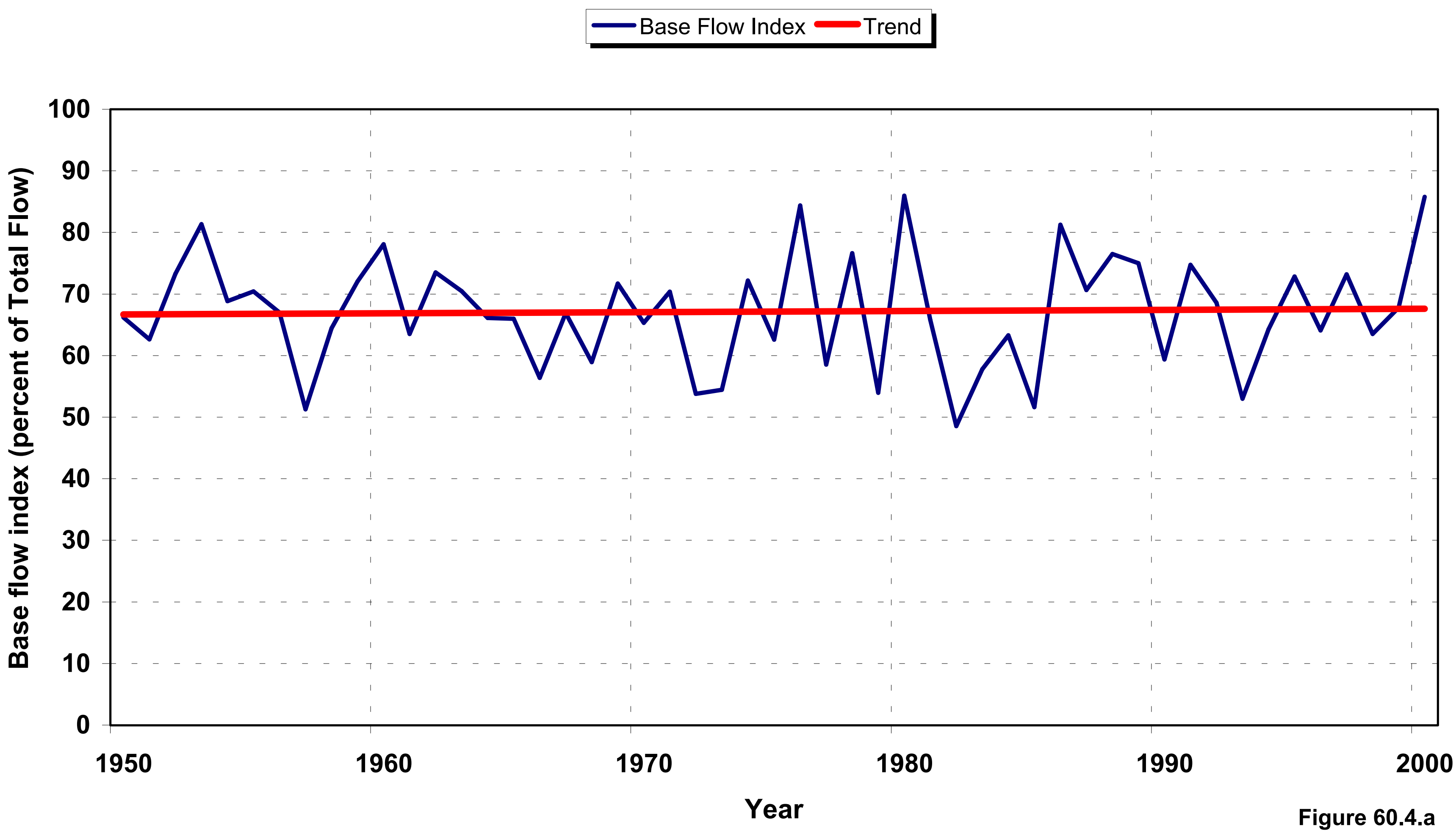


Figure 60.4.a

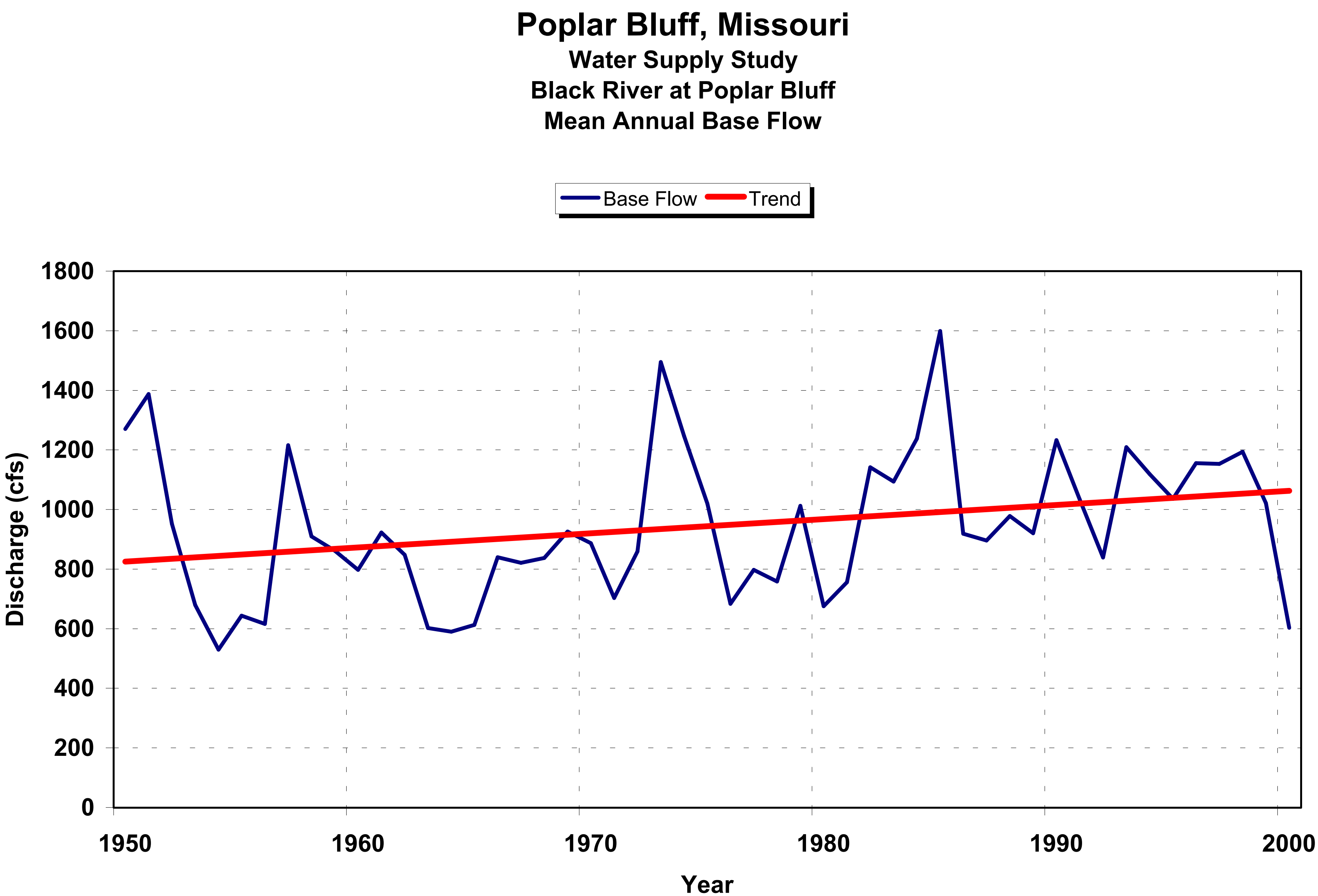

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
Mean Annual Base Flow
Base Flow
Trend
1800
1600
1400
1200
1000
800
600
400
200
0
Discharge (cfs)
1950
1960
1970
1980
1990
2000
Year

Figure 60.4.b

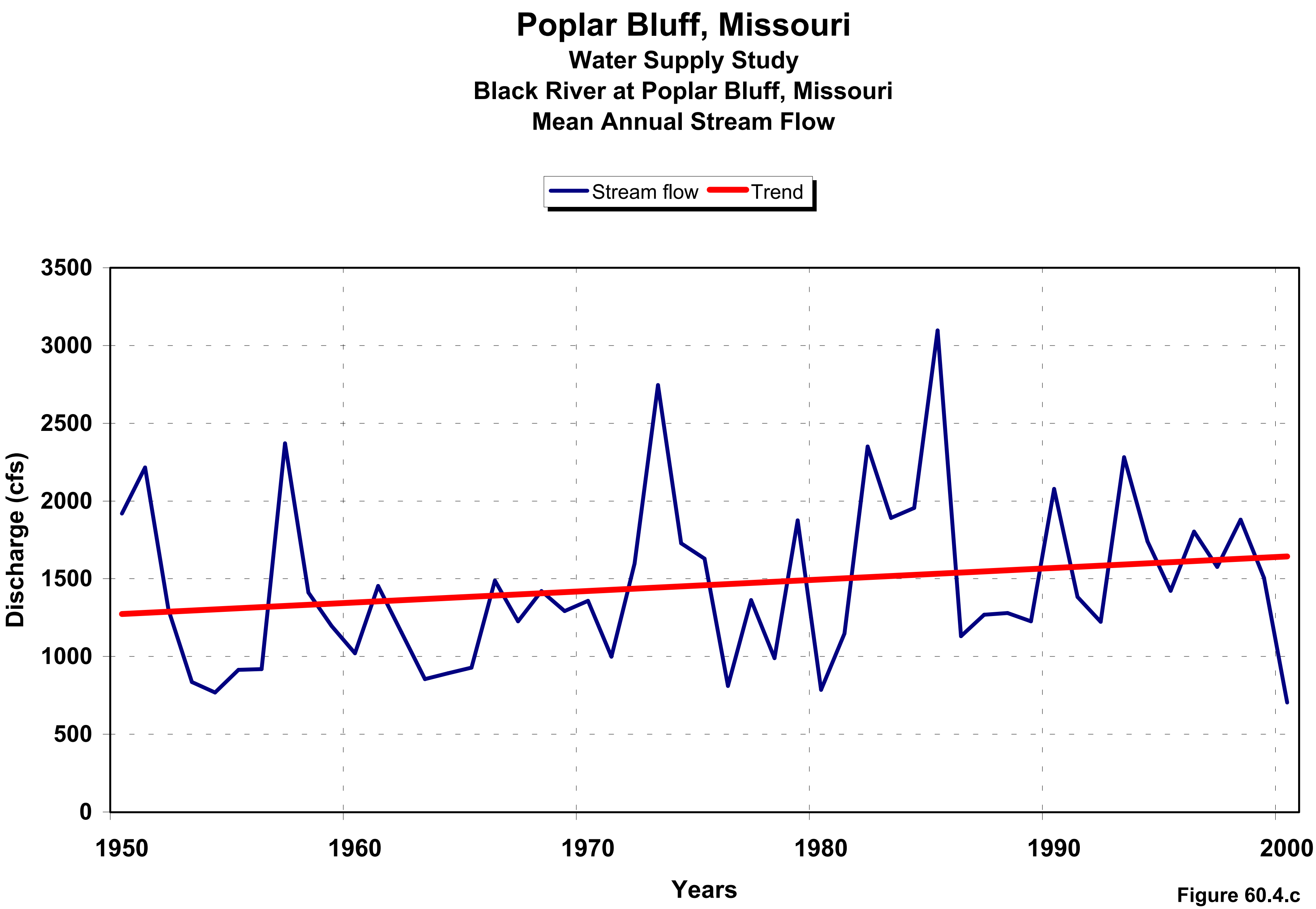

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff, Missouri
Mean Annual Stream Flow
Stream flow
Trend
3500
3000
2500
2000
1500
1000
500
0
Discharge (cfs)
1950
1960
1970
1980
1990
2000
Years

Figure 60.4.c

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
Mean Annual 7 Day Non-Exceedance Low Flow

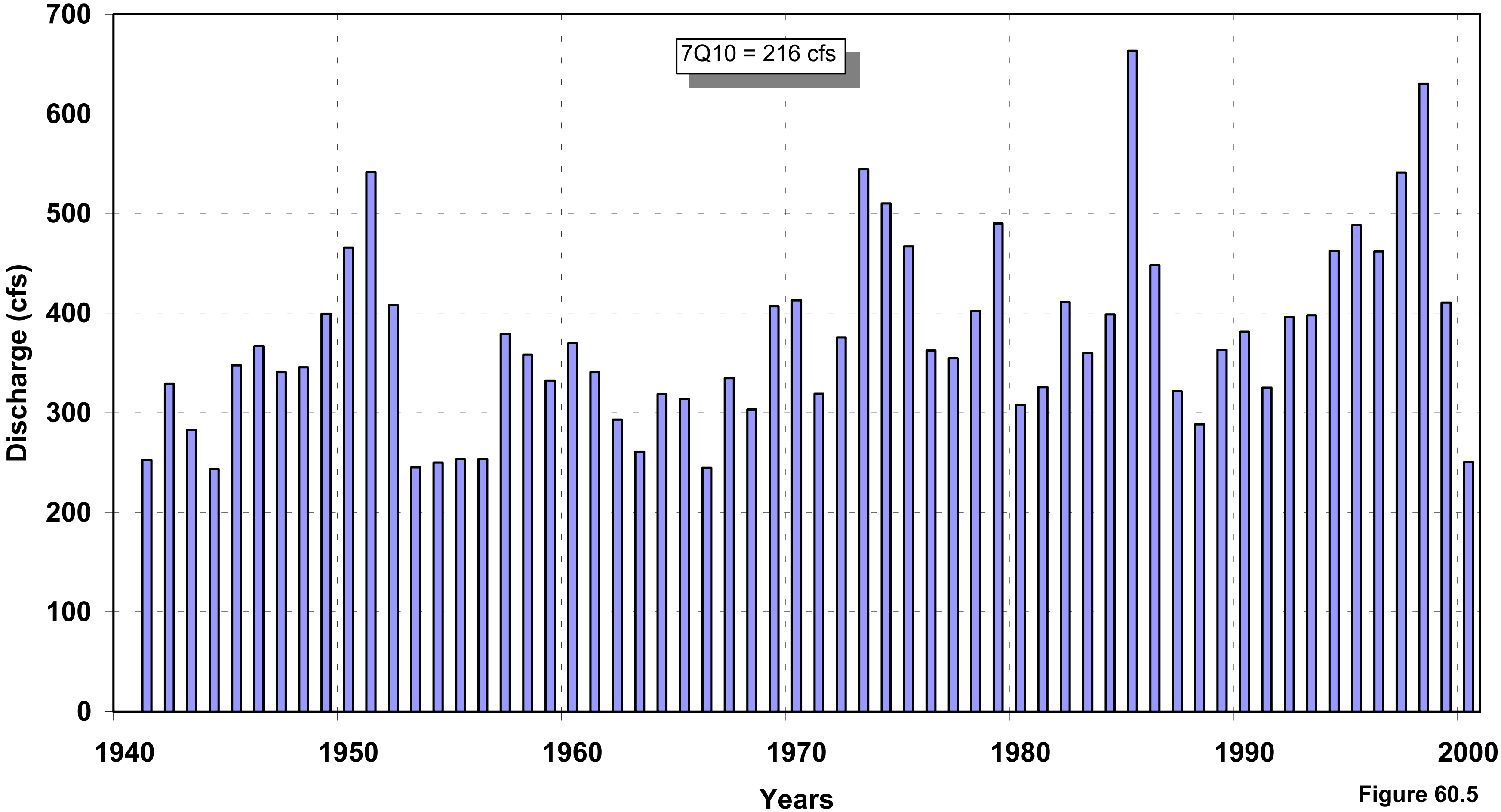


Figure 60.5

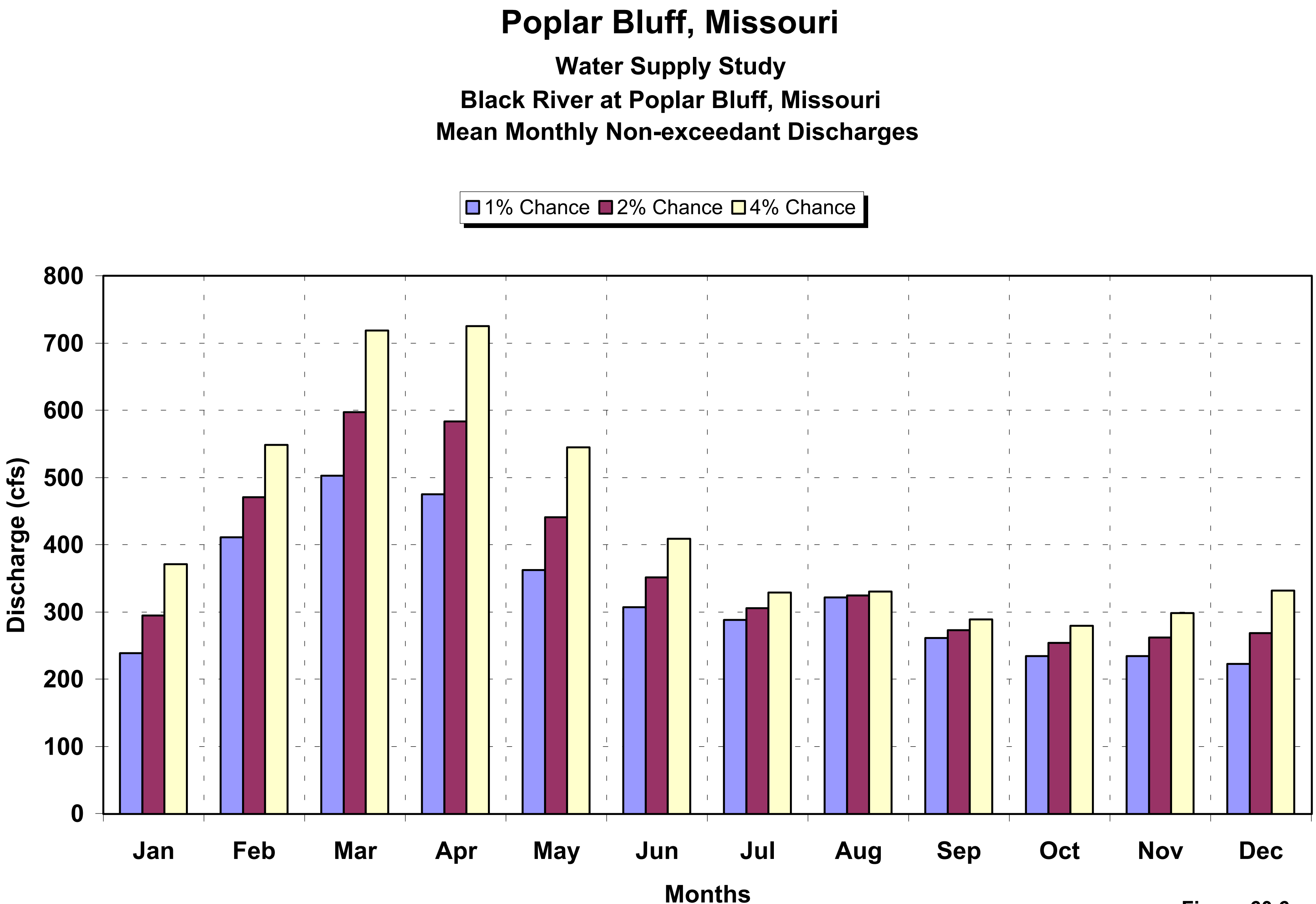

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff, Missouri
Mean Monthly Non-exceedant Discharges
1% Chance
2% Chance
4% Chance
800
700
600
500
400
300
200
100
0
Discharge (cfs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 60.6

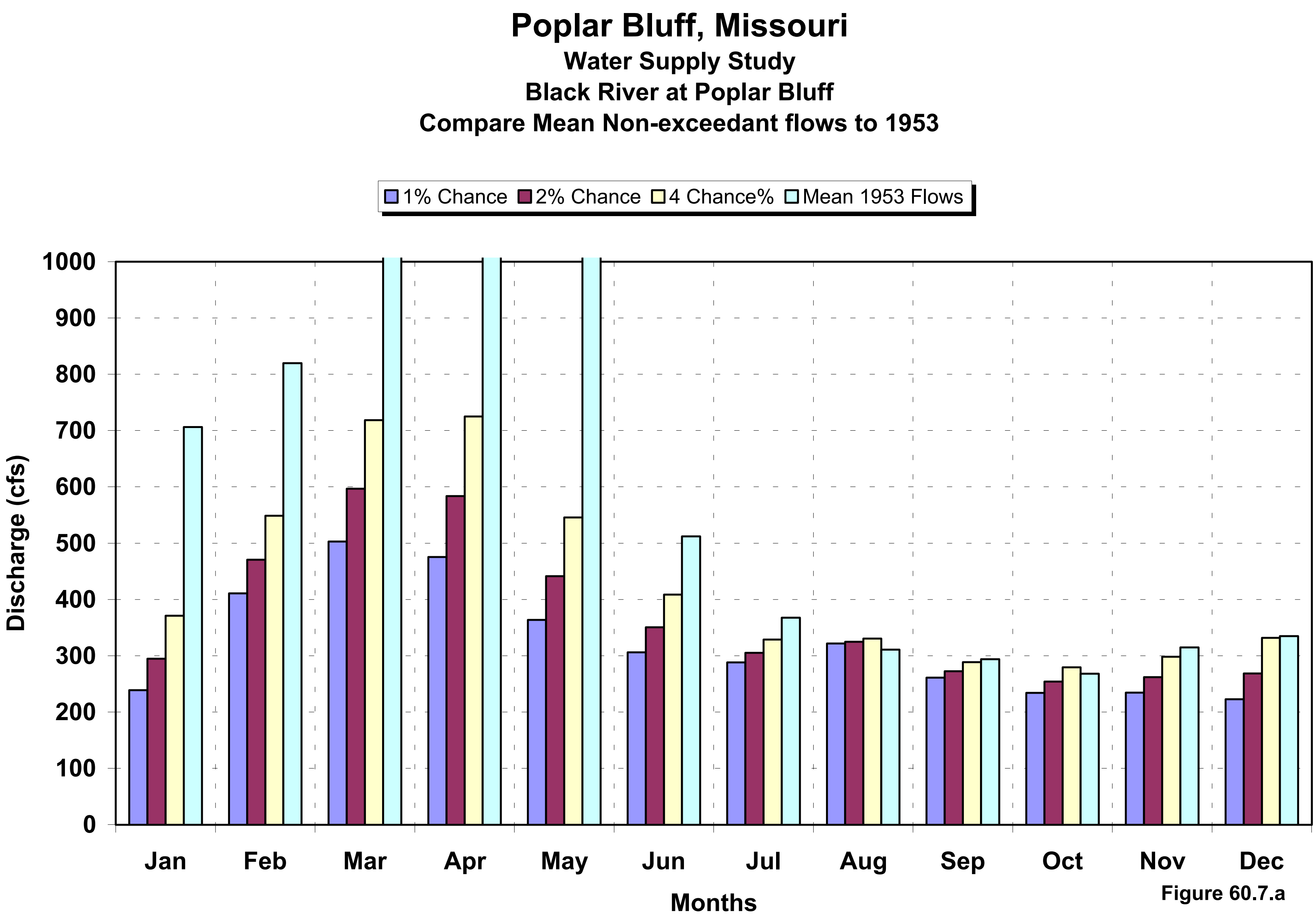

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
Compare Mean Non-exceedant flows to 1953
1% Chance
2% Chance
4 Chance%
Mean 1953 Flows
Discharge (cfs)
1000
900
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 60.7.a

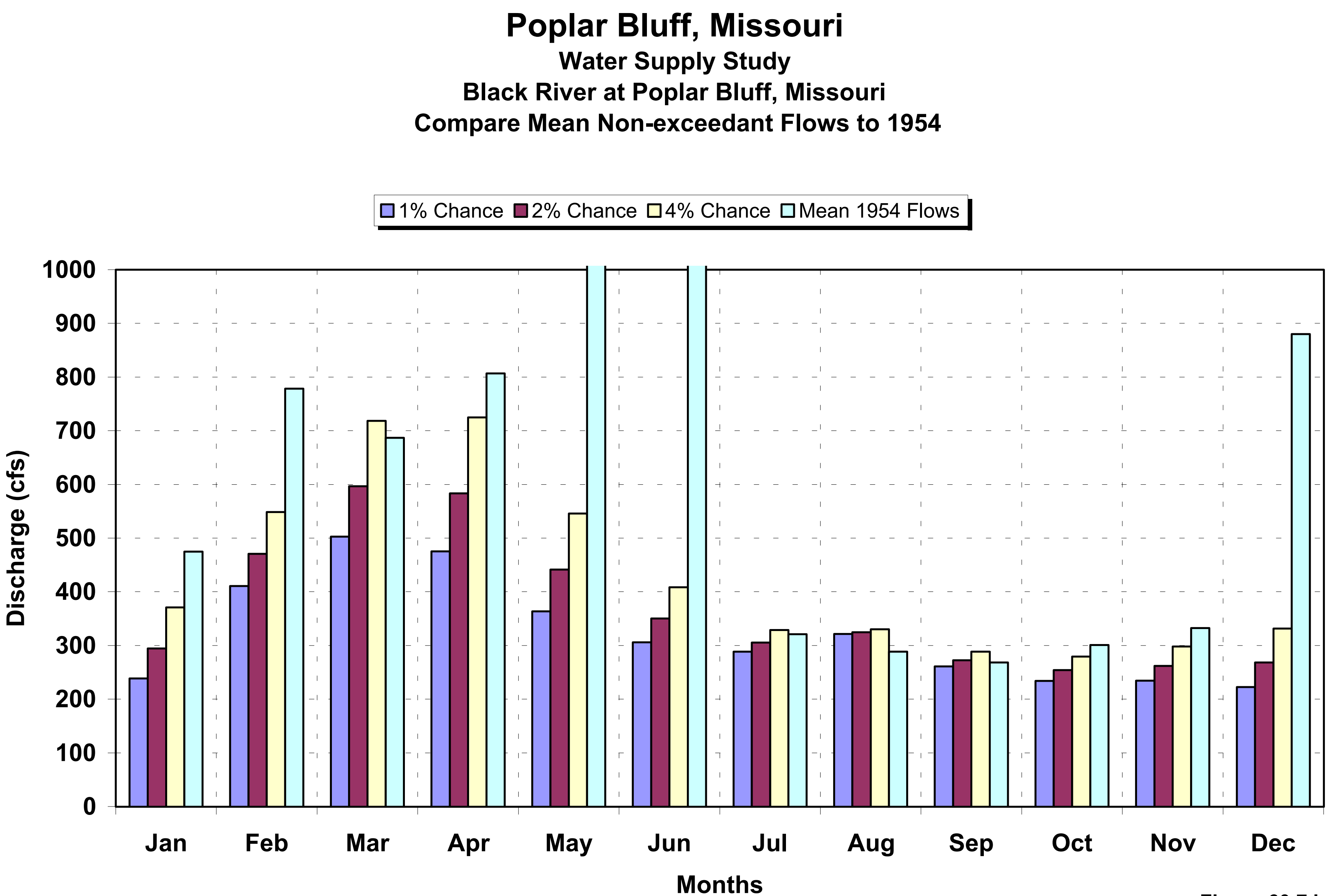

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff, Missouri
Compare Mean Non-exceedant Flows to 1954
1% Chance
2% Chance
4% Chance
Mean 1954 Flows
Discharge (cfs)
0
100
200
300
400
500
600
700
800
900
1000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 60.7.b

Poplar Bluff, Missouri

Water Supply Study

Black River at Poplar Bluff, Missouri

Compare Mean Non-exceedant Flows to 1955

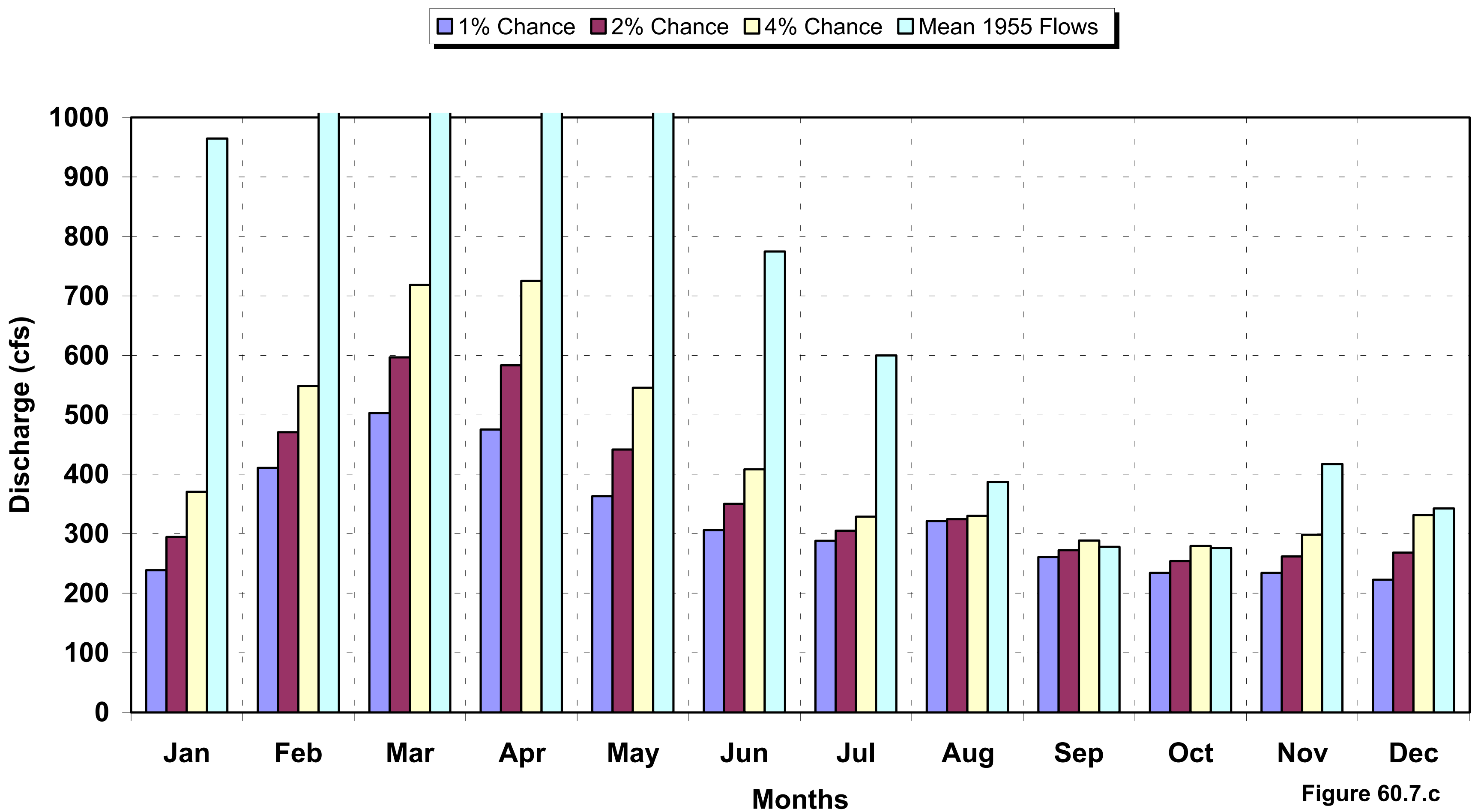


Figure 60.7.c

Poplar Bluff, Missouri

Water Supply Study
Black River at Poplar Bluff, Missouri
Compare Mean Non-exceedant Flows to 1956

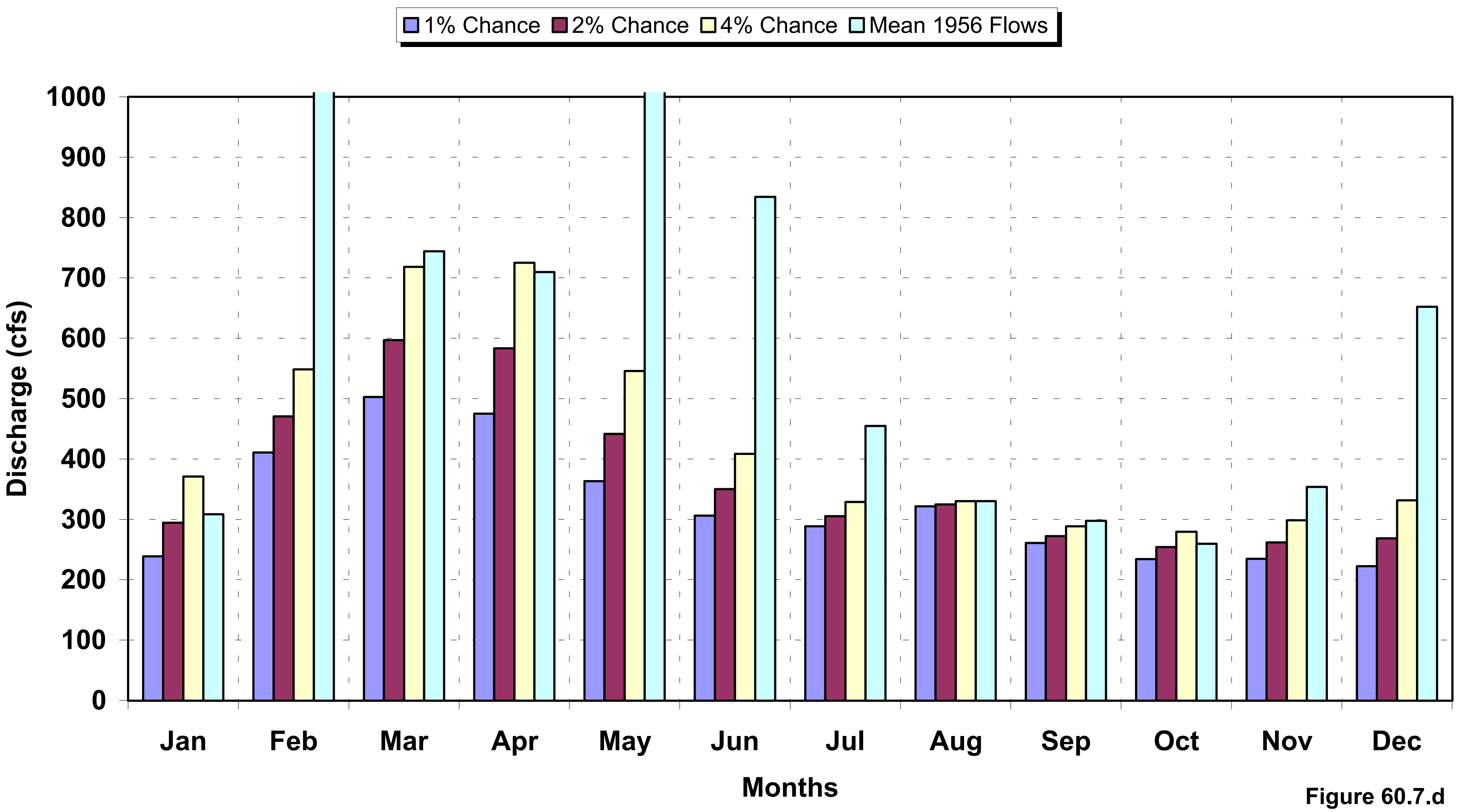


Figure 60.7.d

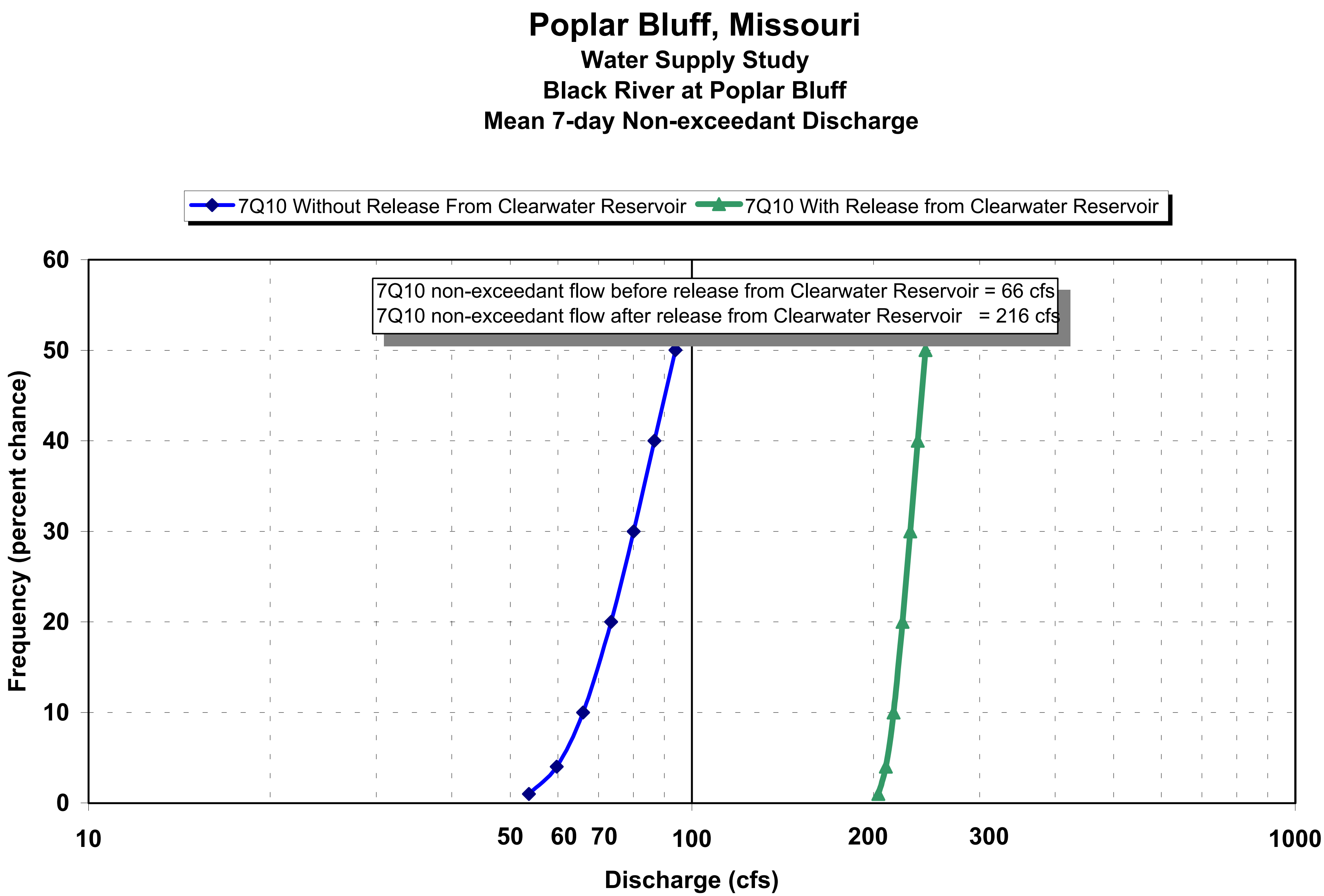

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
Mean 7-day Non-exceedant Discharge
7Q10 Without Release From Clearwater Reservoir
7Q10 With Release from Clearwater Reservoir
7Q10 non-exceedant flow before release from Clearwater Reservoir = 66 cfs
7Q10 non-exceedant flow after release from Clearwater Reservoir = 216 cfs
Frequency (percent chance)
60
50
40
30
20
10
0
10
50
60
70
100
200
300
1000
Discharge (cfs)

Figure 60.8

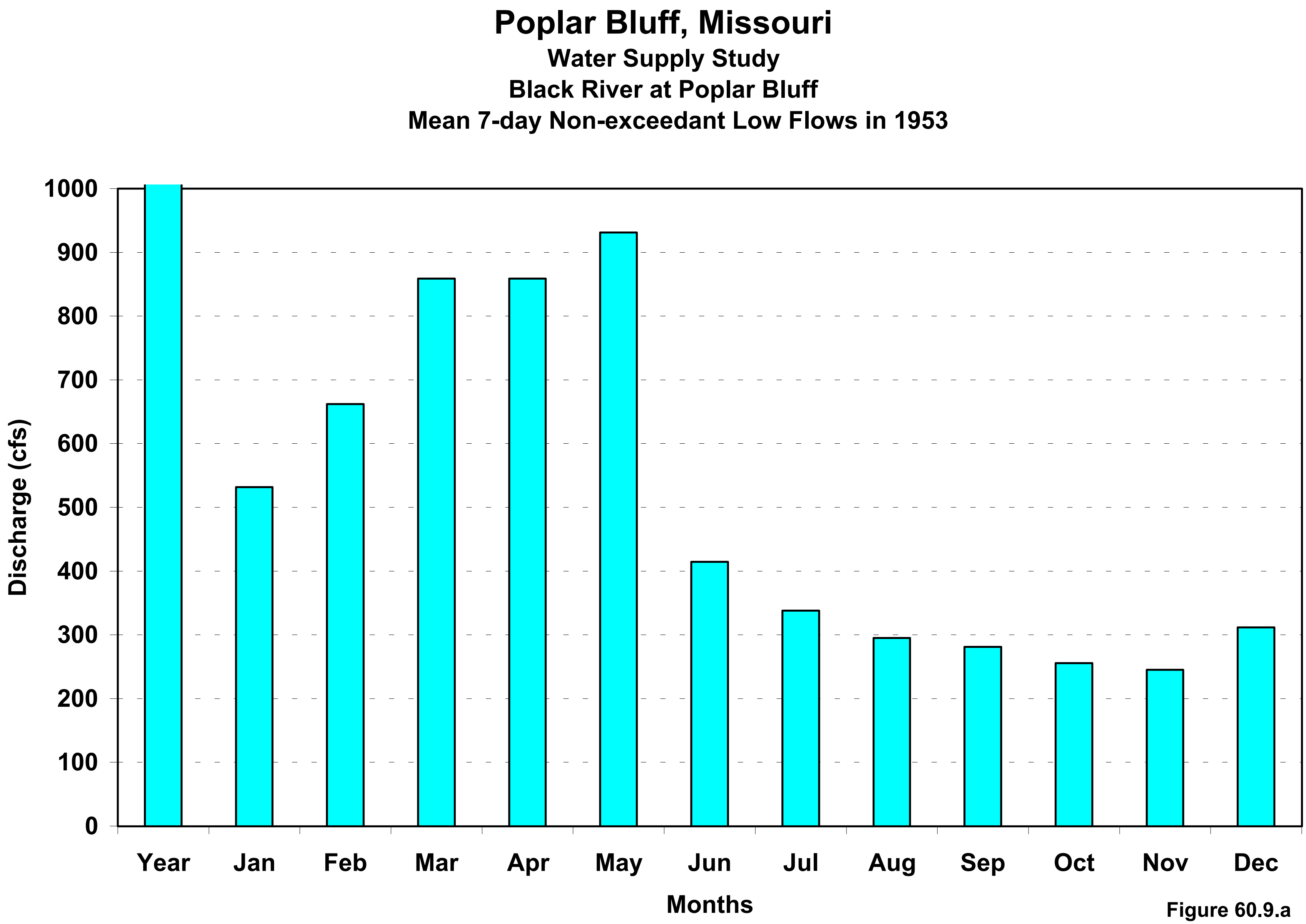

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
Mean 7-day Non-exceedant Low Flows in 1953
Discharge (cfs)
1000
900
800
700
600
500
400
300
200
100
0
Year
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 60.9.a

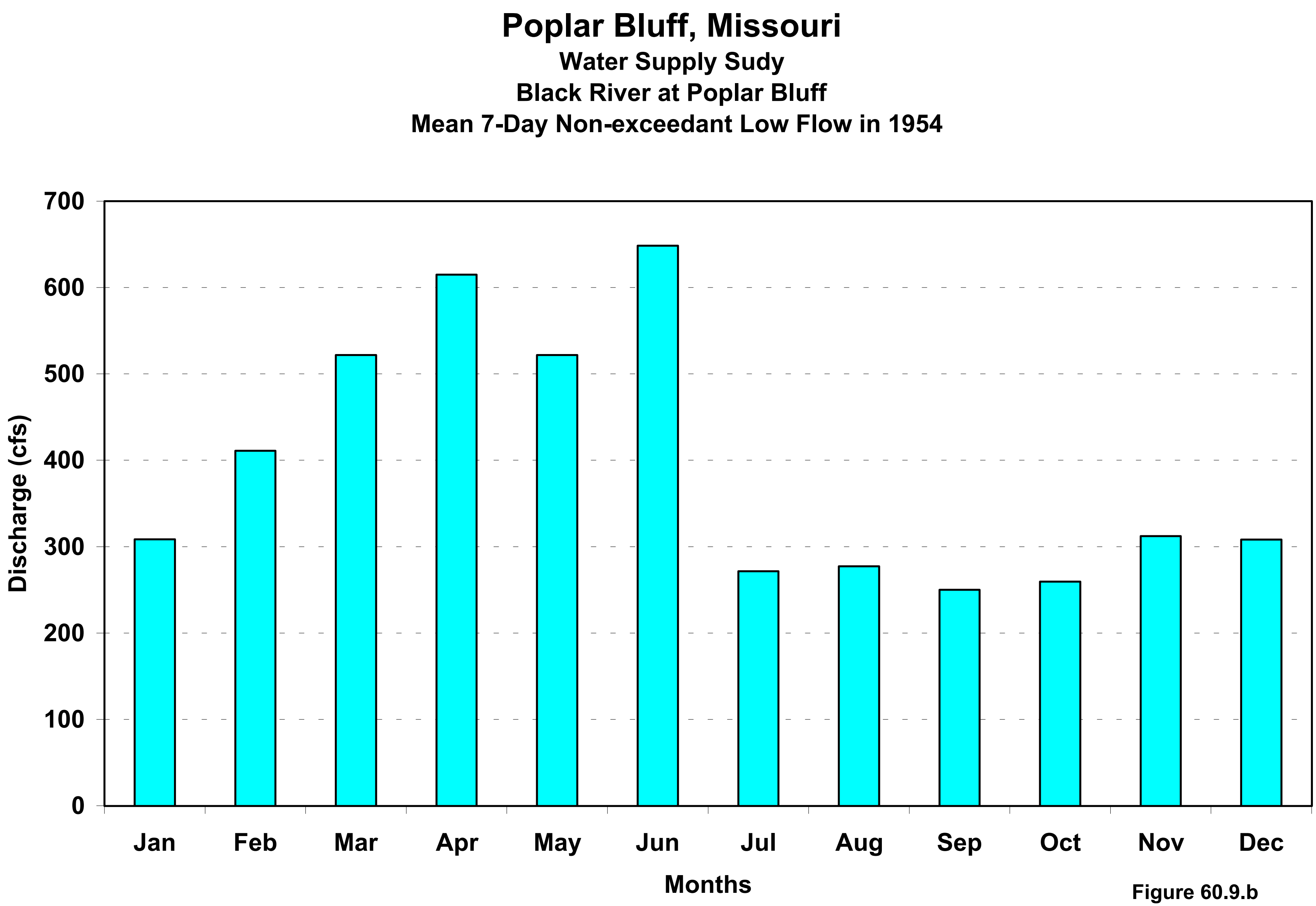

Poplar Bluff, Missouri
Water Supply Sudy
Black River at Poplar Bluff
Mean 7-Day Non-exceedant Low Flow in 1954
Discharge (cfs)
0
100
200
300
400
500
600
700
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 60.9.b

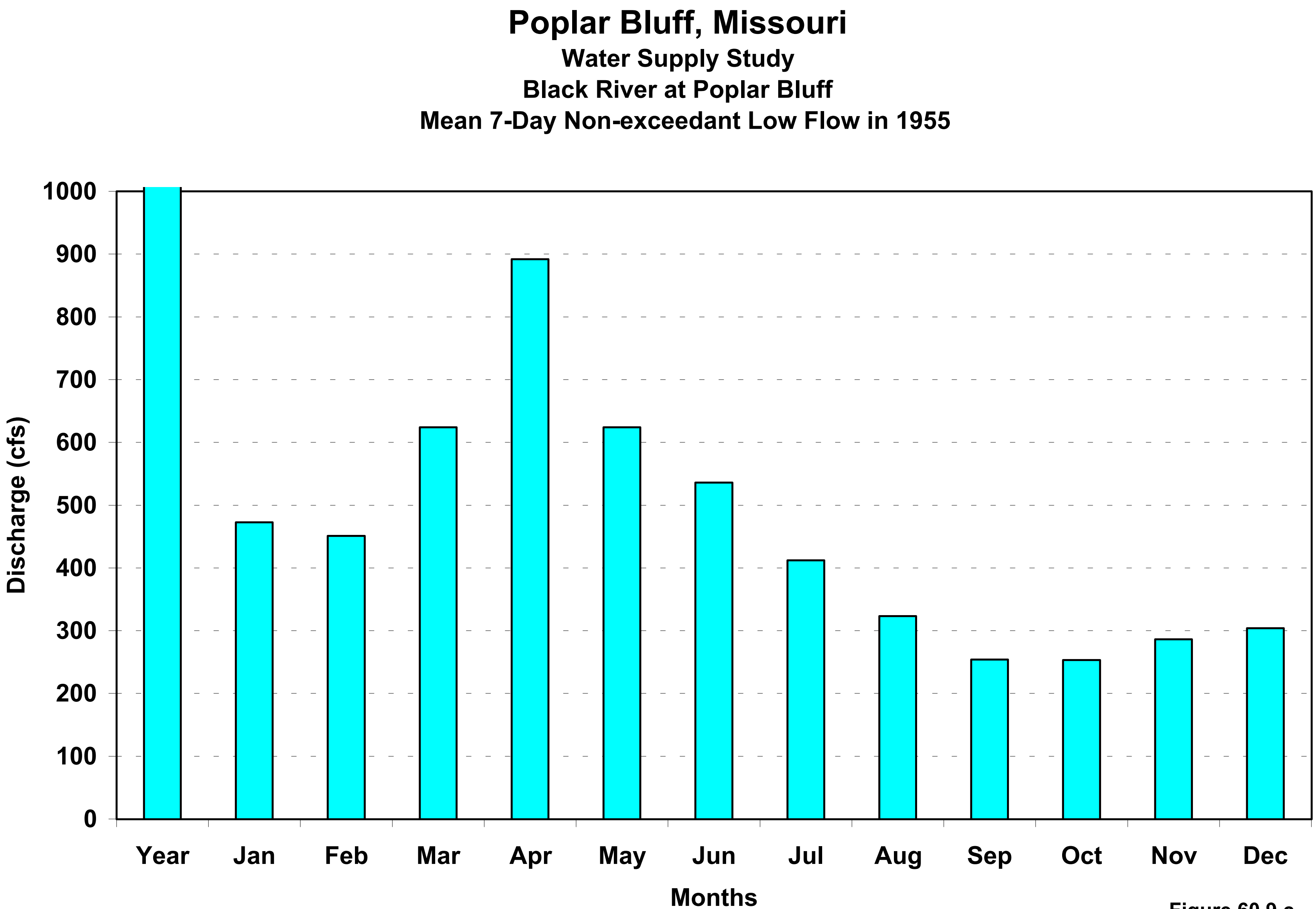

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff
Mean 7-Day Non-exceedant Low Flow in 1955
Discharge (cfs)
1000
900
800
700
600
500
400
300
200
100
0
Year
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 60.9.c

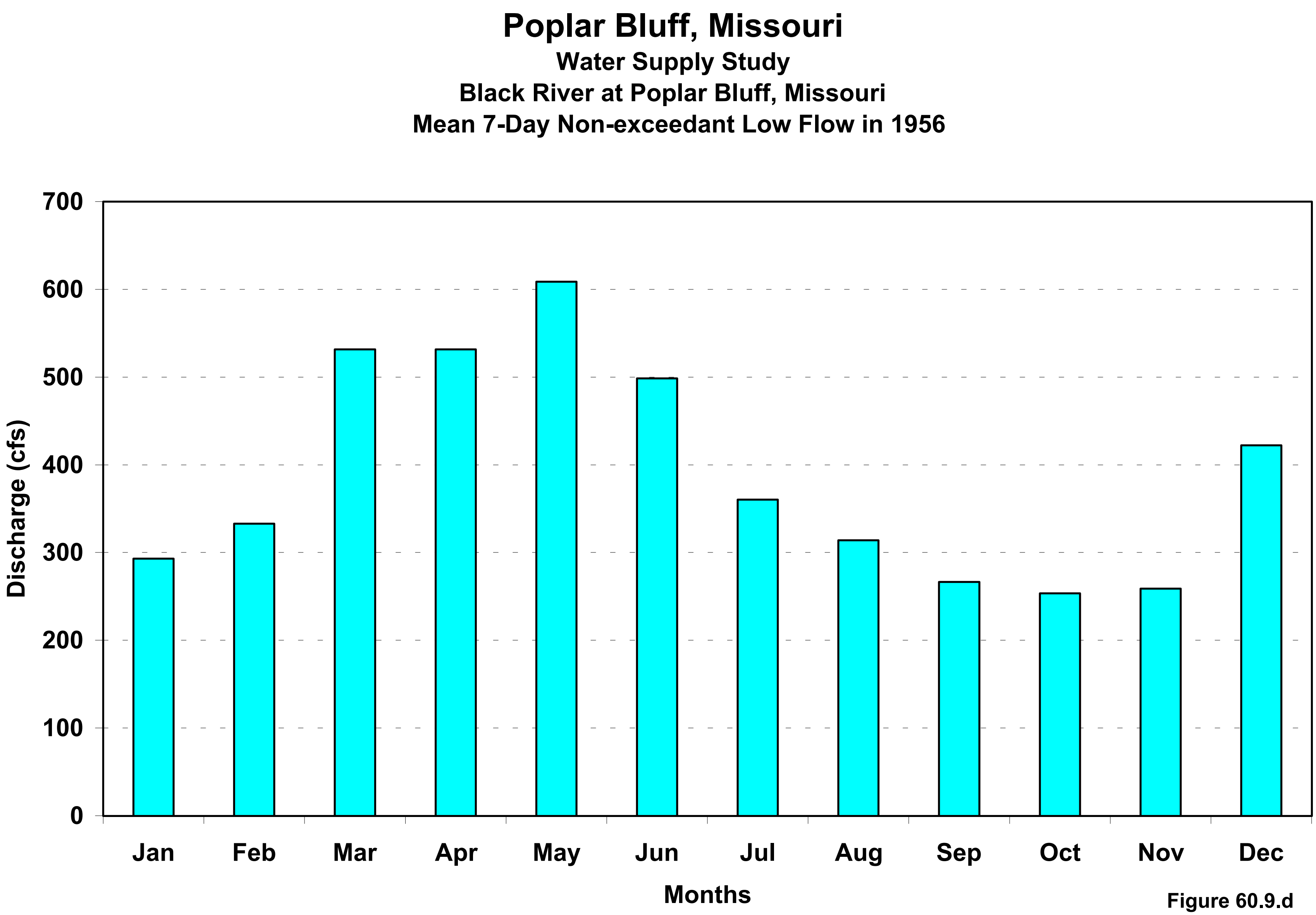

Poplar Bluff, Missouri
Water Supply Study
Black River at Poplar Bluff, Missouri
Mean 7-Day Non-exceedant Low Flow in 1956
700
600
500
400
300
200
100
0
Discharge (cfs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 60.9.d

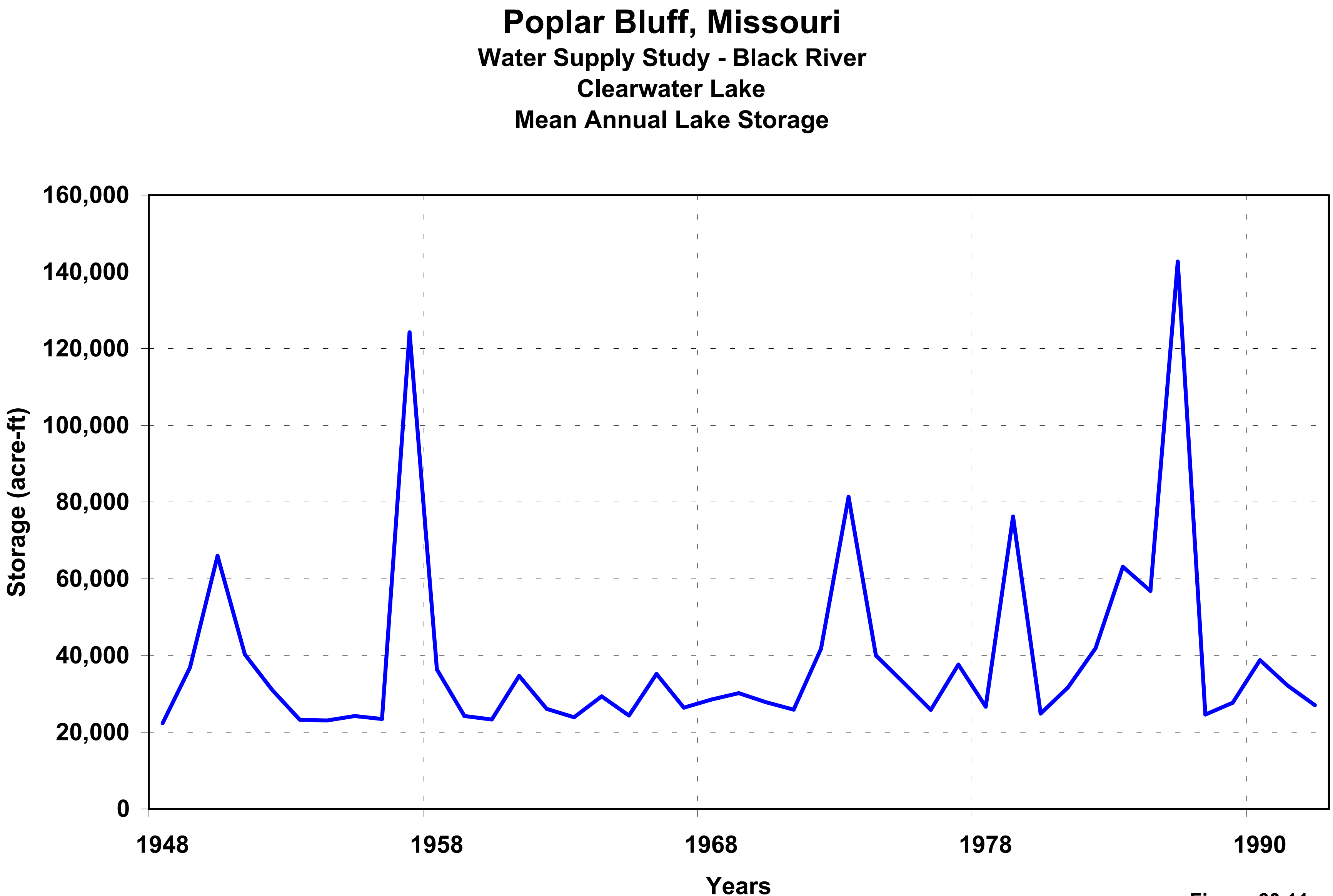

Poplar Bluff, Missouri
Water Supply Study - Black River
Clearwater Lake
Mean Annual Lake Storage
Storage (acre-ft)
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1948
1958
1968
1978
1990
Years

Figure 60.11

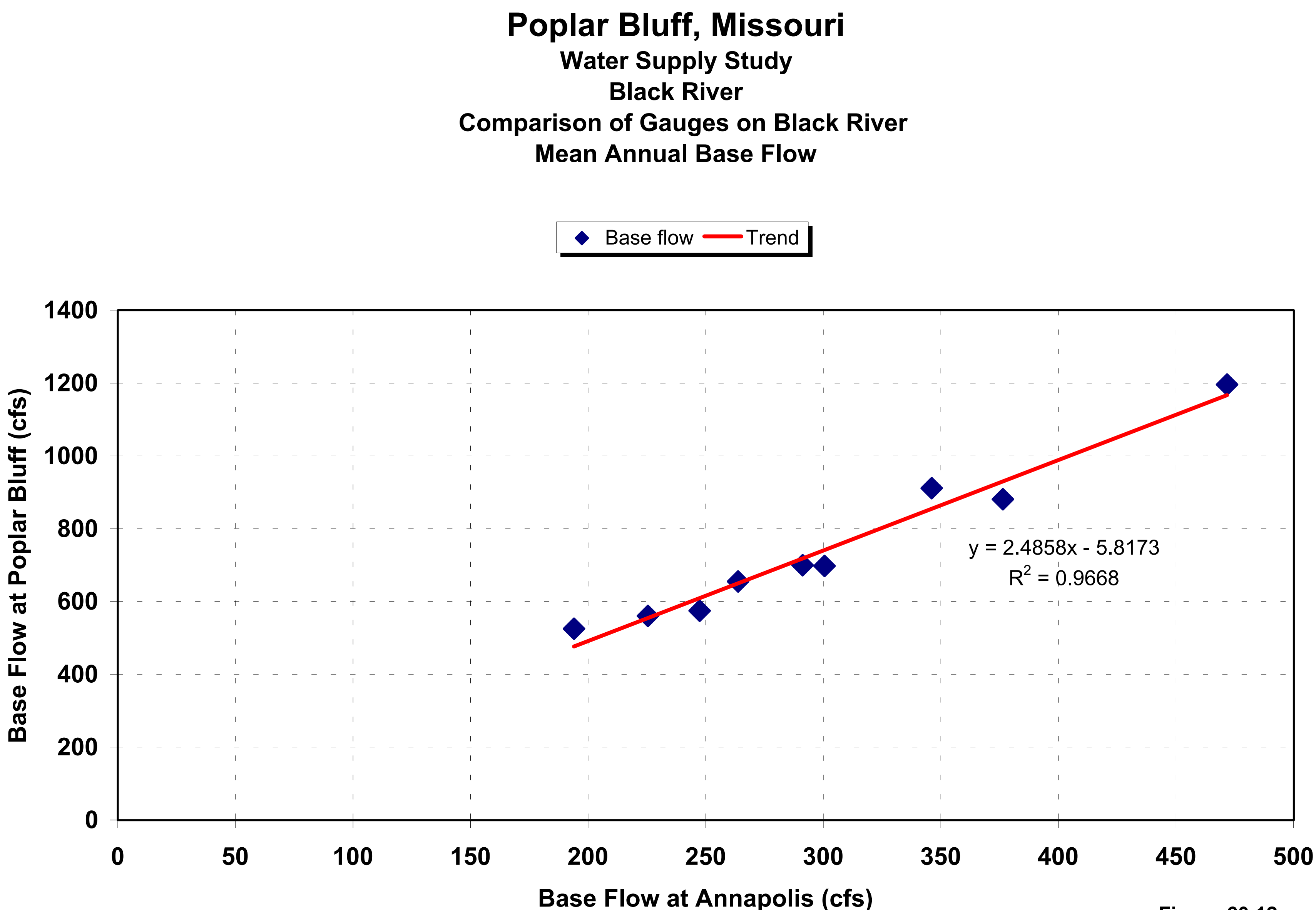


Figure 60.12.a

Poplar Bluff, Missouri
Water Supply Study
Black River
Mean Annual Flows
Comparison of Gauges at Poplar Bluff and Annapolis

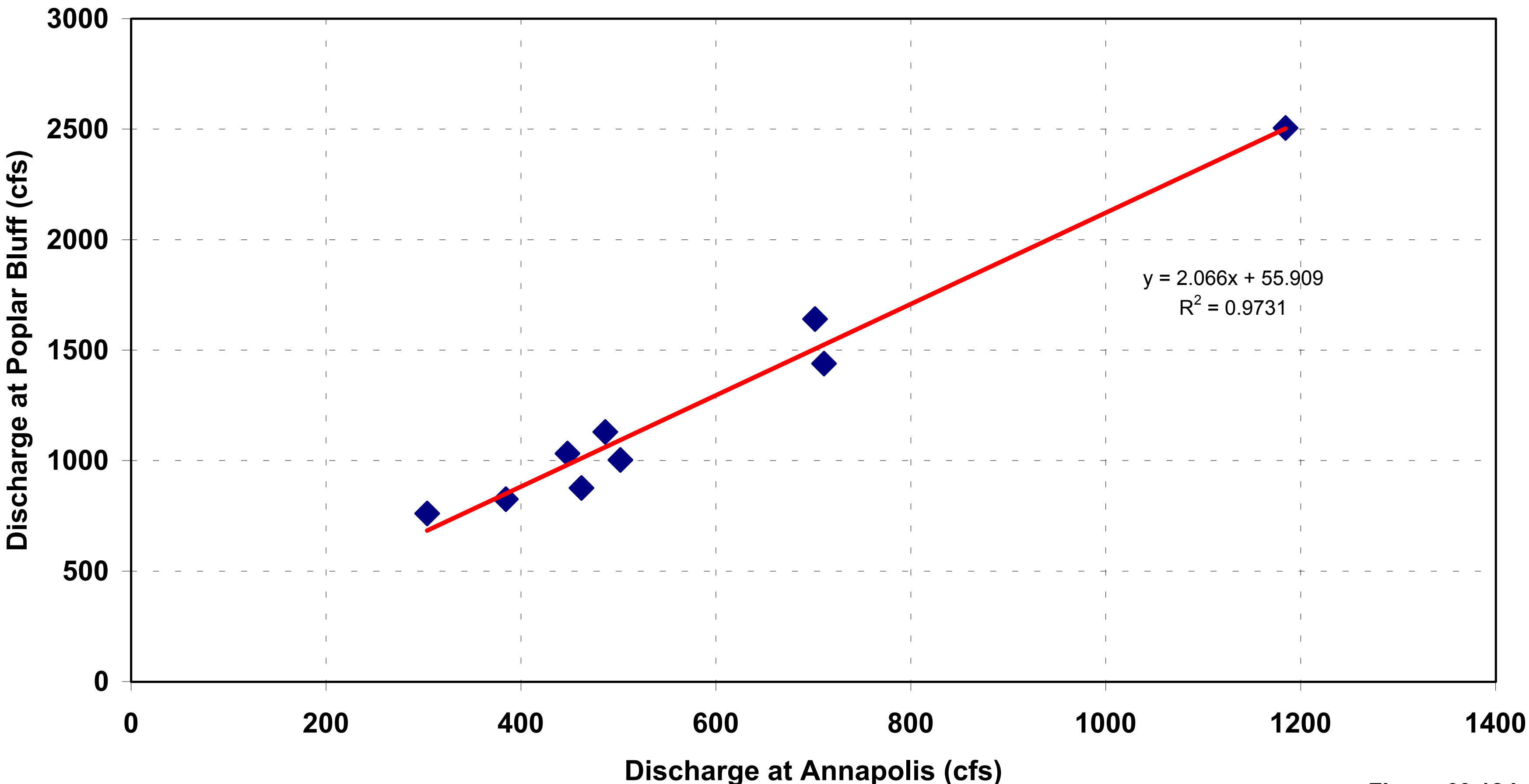


Figure 60.12.b

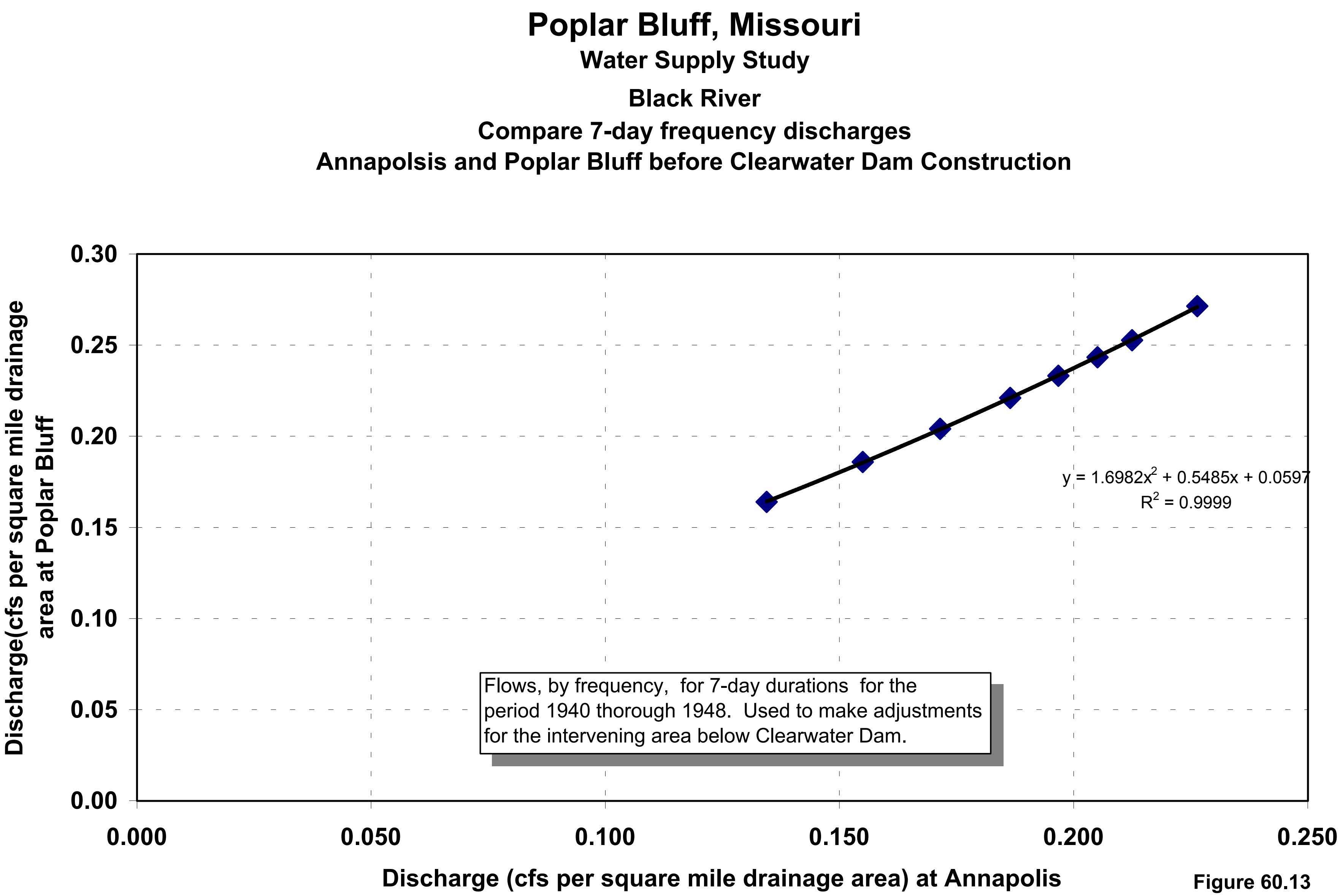

Poplar Bluff, Missouri
Water Supply Study
Black River
Compare 7-day frequency discharges
Annapolsis and Poplar Bluff before Clearwater Dam Construction
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Discharge(cfs per square mile drainage area at Poplar Bluff
0.000
0.050
0.100
0.150
0.200
0.250
Discharge (cfs per square mile drainage area) at Annapolis
y = 1.6982x2 + 0.5485x + 0.0597
R2 = 0.9999
Flows, by frequency, for 7-day durations for the period 1940 thorough 1948. Used to make adjustments for the intervening area below Clearwater Dam.

Figure 60.13

Trenton, Missouri
Water Supply Study
Thompson River

Overview

This analysis was made to assess the availability of Trenton's water supply. Trenton gets their water supply from Thompson River. Thompson River stream gauge at Trenton, drainage area 1670 square miles is located approximately one mile downstream of the pump intake. Analysis indicates insufficient instream supply to meet demand during an extended multi-year drought such as the 1950's

Two pumps, pump from Thompson River to two water storage basins, each pump is rated at 3125 gallons per minute (gpm). They use one at a time and keep the other in reserve. 3125 gpm is near treatment plant capacity of 4.5 million gallons per day (mgd). The south basin has a surface area if 13.5 acres with storage capacity of 75.3 acre-feet (24.5 million-gallon). The maximum depth is 20 feet. The north basin has a surface area of 34.9 acres with storage capacity of 430 acre-feet (140 million-gallon). The maximum depth is 17 feet. The operating procedure is to keep the basins as near full as possible. When using water at treatment plant capacity of 4.5 mgd the supply in the basins would be used up in 36 days with no additional inflow. Figure 70.1 shows that the long-term trend (1983 through 2001) daily water usage increased from approximately 1.5 mgd in 1983 to 1.75 mgd in 2001, resulting in a daily increase in demand of 17 percent. Historical use from 1995 through 2001 increased from 1.38 mgd to 1.90 mgd, and increase of 38 percent. Maximum water usage of 2.055 mgd occurred in 1993. At this demand there would be 80 days of water stored in the basins.

Stream flow data was obtained from USGS water supply papers. Mean daily discharges were used to analyze stream flow volumes and frequencies. Continuous records have been kept from 1928 through 2002. For this report, all statistical determinations were made using the Log Pearson type III method as described in Water Resource Council bulletin 17B.

Drought Assessment:

Annual precipitation amounts for most of Missouri have been increasing during the last 50 years. This is shown in the state water plan. The study was recently made for the state by Steve Hu (former state climatologist at University of Missouri) to update climate data**.** Figures 70.2.a and 70.2.b illustrate the precipitation trend for two gauges near the center of the Thompson River drainage basin. One gauge is at Princeton, Missouri and the other at Lamoni, Iowa. These station trends show 50-year precipitation increases of 23 percent at Princeton to 32 percent at Lamoni for years 1950 through 2000. Figure 70.3.a shows the effect of increased annual rainfall on runoff. The trend indicates an increase in total annual runoff from 7.5 watershed inches to 10 inches or approximately 33 percent from 1955 to year 2000. Figure 70.3.b is the mean annual runoff discharge in terms of cubic feet per second (cfs).

Base flow separation was made using the USGS computer program, HYSEP. This analysis was made to estimate sustained flow, in order to establish availability of continuous stream flow. Figure 70.4.a is the base flow index and is the ratio of base flow to total stream flow. This chart shows the yearly fluctuation in base flow indexes and indicates the trend. The trend shows an increase from 26 percent of total annual runoff in 1955 to 38 percent in 2000. The increase in annual base flow volume in terms of watershed inches is shown in figure 70.4.b. Figure 70.4.c illustrates the base flow in terms of mean annual cubic feet per second (cfs).

Mean seven-day annual low flows for 1928 through 1999 were calculated and are shown in figure 70.5. The lowest 7-day discharge occurred in 1956 with a mean value of 2 cfs for the year.

Monthly non-exceedance probabilities for 1%, 2% and 4% chance of occurring were established from stream flow data for the years 1950 through 2000. Figure 70.6 displays the 1%, 2% and 4% Chance mean monthly low flow. The 4% chance indicates discharges to be sufficiently high to allow withdrawal throughout the year.

The drought of record was in the 1950's. Mean non-exceedance probabilities for the 1%, 2% and 4% chance flows shown in Figure 70.6 are compared to actual stream flow records in figures 70.7.a through 70.7.d for the drought of record (1954 through 1957). These monthly runoff volumes for 1954, 1955, 1956 and 1957 were obtained from USGS stream flow records. These figures show that mean monthly discharge in Thompson River falls below the 7Q10 frequency low flow (9 cfs) for 3 months. These occur in January 1954 when discharge = 7.1 cfs, December 1955 discharge = 6.5 cfs and January 1956 discharge = 4.7 cfs.

Figure 70.7.a compares 1954 mean monthly flow to monthly probability shown in figure 70.6.

Figure 70.7.b compares 1955, Figure 70.7.c compares 1956, and Figure 70.7.d compares 1957 values.

To assure that water quality standards are met most of the time, the mixing zone flow is based on the seven-day average low flow that has a recurrence interval of once in 10 years (7Q10). To determine the rate of flow needed to meet in-stream flow requirements, the 7Q10 determined using the period of record, 1950 through 2000. Figure 40.8 shows the results of the frequency analysis to be 9 cfs. For purposes of diverting water from the creek, discharge needs to exceed 9 cfs.

Additional comparisons for the 1950's drought were made using the mean 7-day low flow for examining a shorter duration. These comparisons are shown in figures 70.9.a, 70.9.b, 70.9.c and 70.9.d. These figures show the critical months for each year. In the 4-year period of 1954 through 1957 there were 12 months that had mean seven-day flows below 7Q10 frequency discharge of 9 cfs. They were:

1954 - 3 months January (4 cfs), February (4 cfs), September (8 cfs).
1955 - 3 months September (6cfs), November (8 cfs), December (5 cfs).
1956 - 5 months January (4 cfs), February (5 cfs), April (4 cfs), May (3 cfs) and June (2cfs).
1957 - 1 month October (6 cfs).

Deficits shown in the following displays are the volume shortages necessary to meet the 7Q10 needs and municipal demand. Figure 70.10.a shows non-exceedance probability flows of the 1% chance of occurrence and indicates that half of the months, March through August exceed the 7Q10 discharge, The remaining months were below the 7Q10 flow rate. Figure 70.10.b is the 2 percent chance low flows and indicates only three months are close to 7Q10 discharge, and they would have enough carry over storage in the reservoirs to provide adequate water. Figure 70.10.c shows the 4% chance of occurrence is able to provide enough flow so that there would be no deficit. Figures 70.10.d and 70.10.e display the deficits in bar charts, one showing the deficit in acre-feet and the other in terms of cfs.

Water usage for the seven-year period of 1995 through 2001was reported to be:

1995…..1.38 mgd
1996…..1.62 mgd
1997…..1.47 mgd
1998…..1.51 mgd
1999…..1.64 mgd
2000…..1.84 mgd
2001…..1.90 mgd

Conclusions:

Mean monthly Thompson River discharges will be less than the 7Q10 discharge of 9 cfs for the 1% chance or 1 year in 100 years low flows for six months of January, February, and September through December. For the 2% chance or 1 year in 50 years, these same months were very close to the 7Q10 flow with January and December being slightly less and 4 months had flows approximately equal to the minimum 9 cfs. The indication here is to keep the reservoirs full of water.

During the 1950's there were no months that flow in Thompson River would not allow some pumping at the rated pump capacity of 3125 gallon per minute (6.96 cfs) for at least some of the month. However there would be longer periods of time flows would be too low for pumping. This is indicated by the 7-day low mean discharge values for 1954, 1955, 1956 and 1957. Each year had mean 7-day duration flows below pump ratings.

Trenton's demand is increasing at a long-term rate of 0.013 mgd. The present system is meeting their needs. The treatment plant is able to treat 4.5 mgd and the current demand is less than 2 mgd. Between years 1928, when the stream gauge on Thompson River was installed, to year 2001 there were five 30 day periods when pumping from the river to the reservoirs could not occur. These were all in 1956 or earlier. They are July 1954, January 1940, December 1955 and January 1956, as well as May 1956. With the storage in the reservoirs, City demand could be met during the 30-day dry periods.

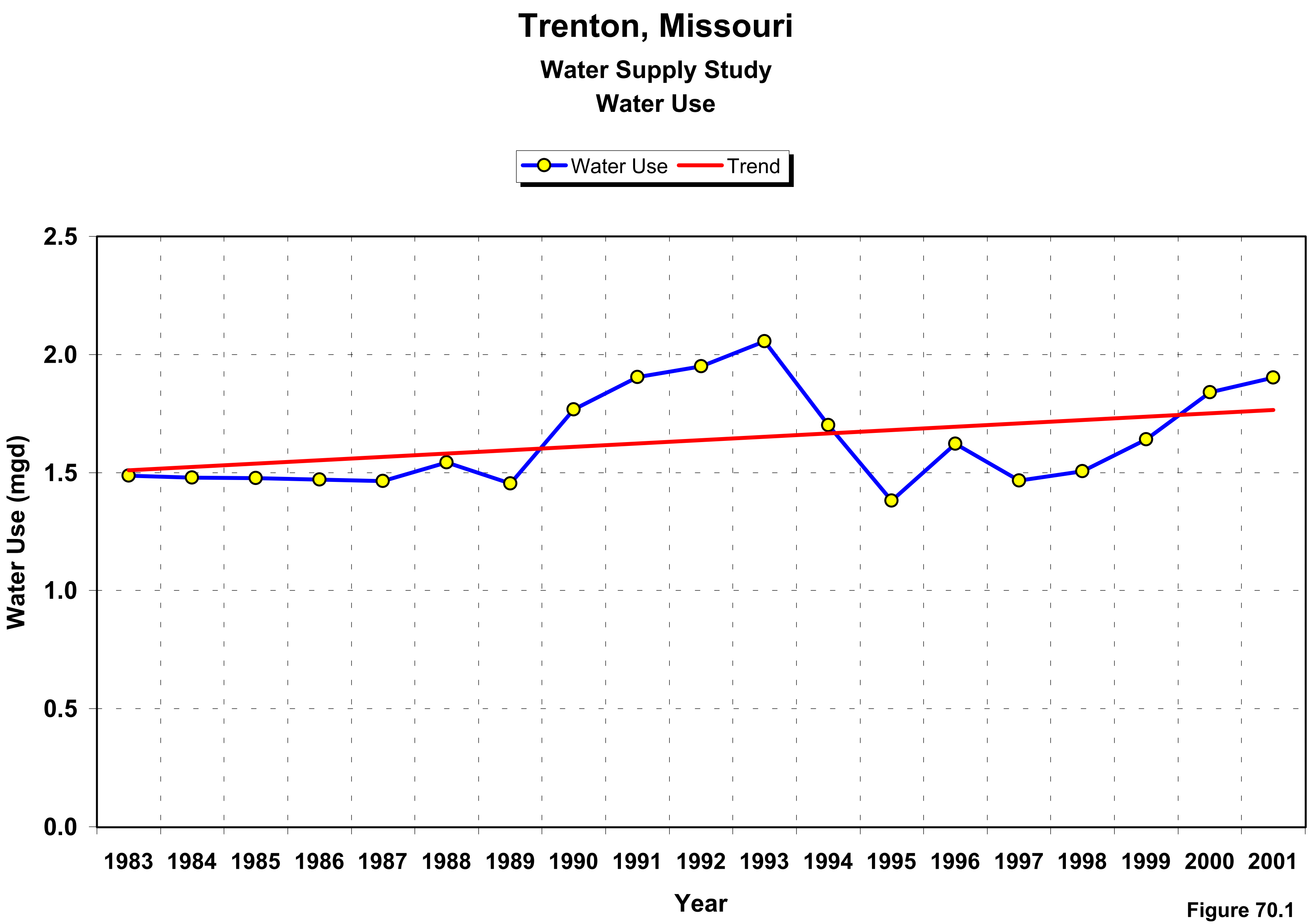

Trenton, Missouri
Water Supply Study
Water Use
Water Use
Trend
2.5
2.0
1.5
1.0
0.5
0.0
Water Use (mgd)
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 70.1

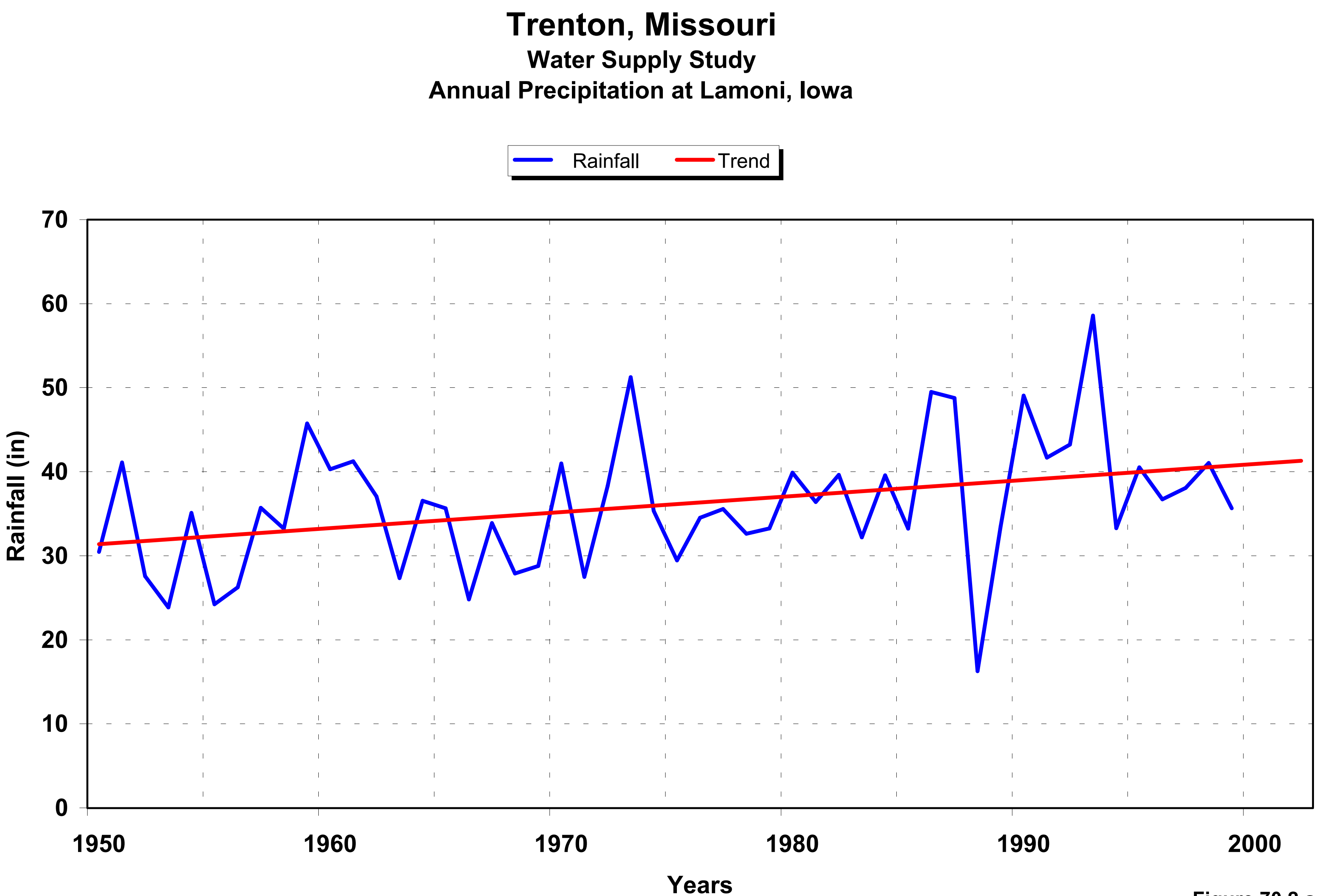

Trenton, Missouri
Water Supply Study
Annual Precipitation at Lamoni, Iowa
Rainfall
Trend
70
60
50
40
30
20
10
0
Rainfall (in)
1950
1960
1970
1980
1990
2000
Years

Figure 70.2.a

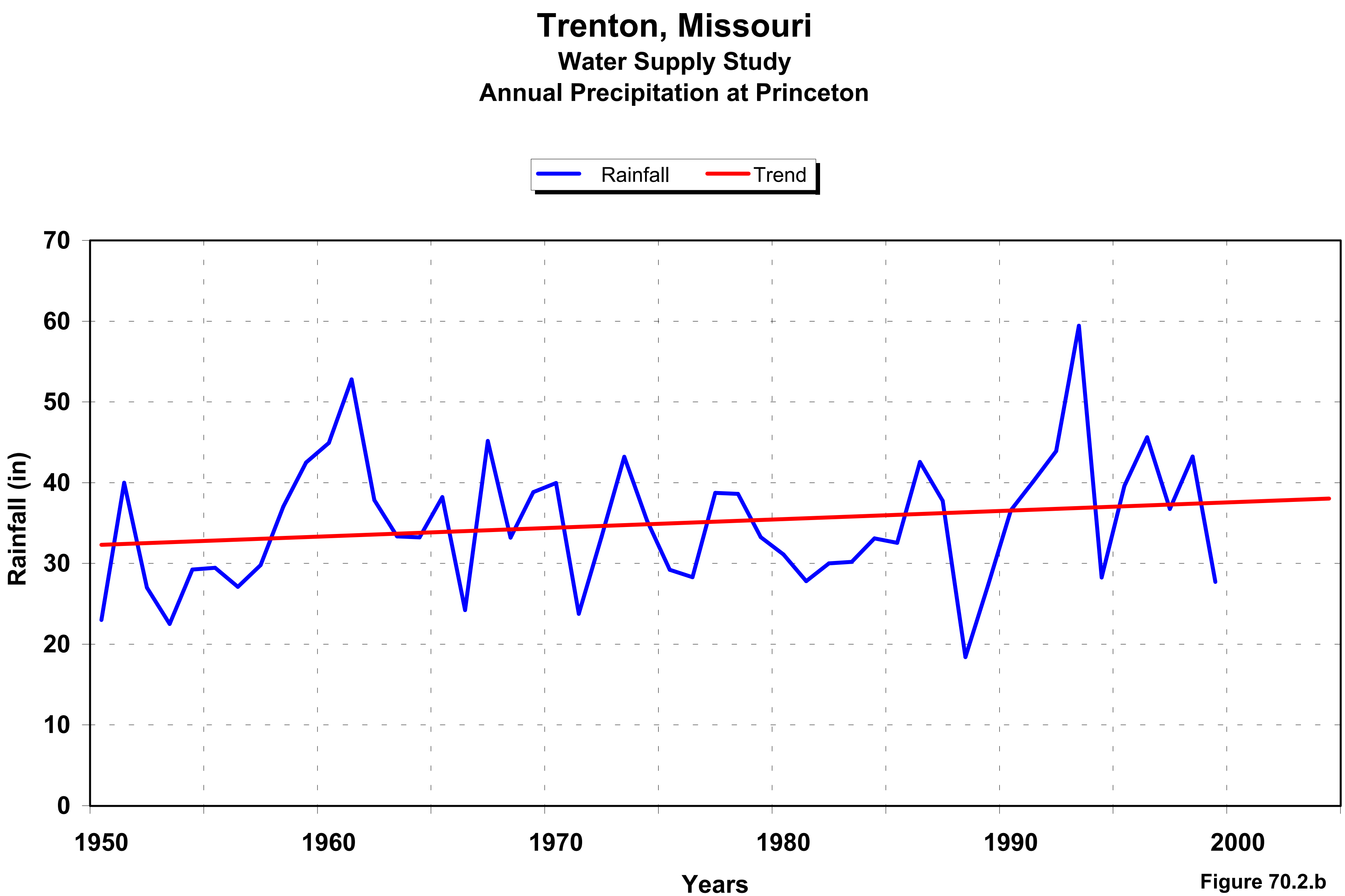

Trenton, Missouri
Water Supply Study
Annual Precipitation at Princeton
Rainfall
Trend
70
60
50
40
30
20
10
0
Rainfall (in)
1950
1960
1970
1980
1990
2000
Years

Figure 70.2.b

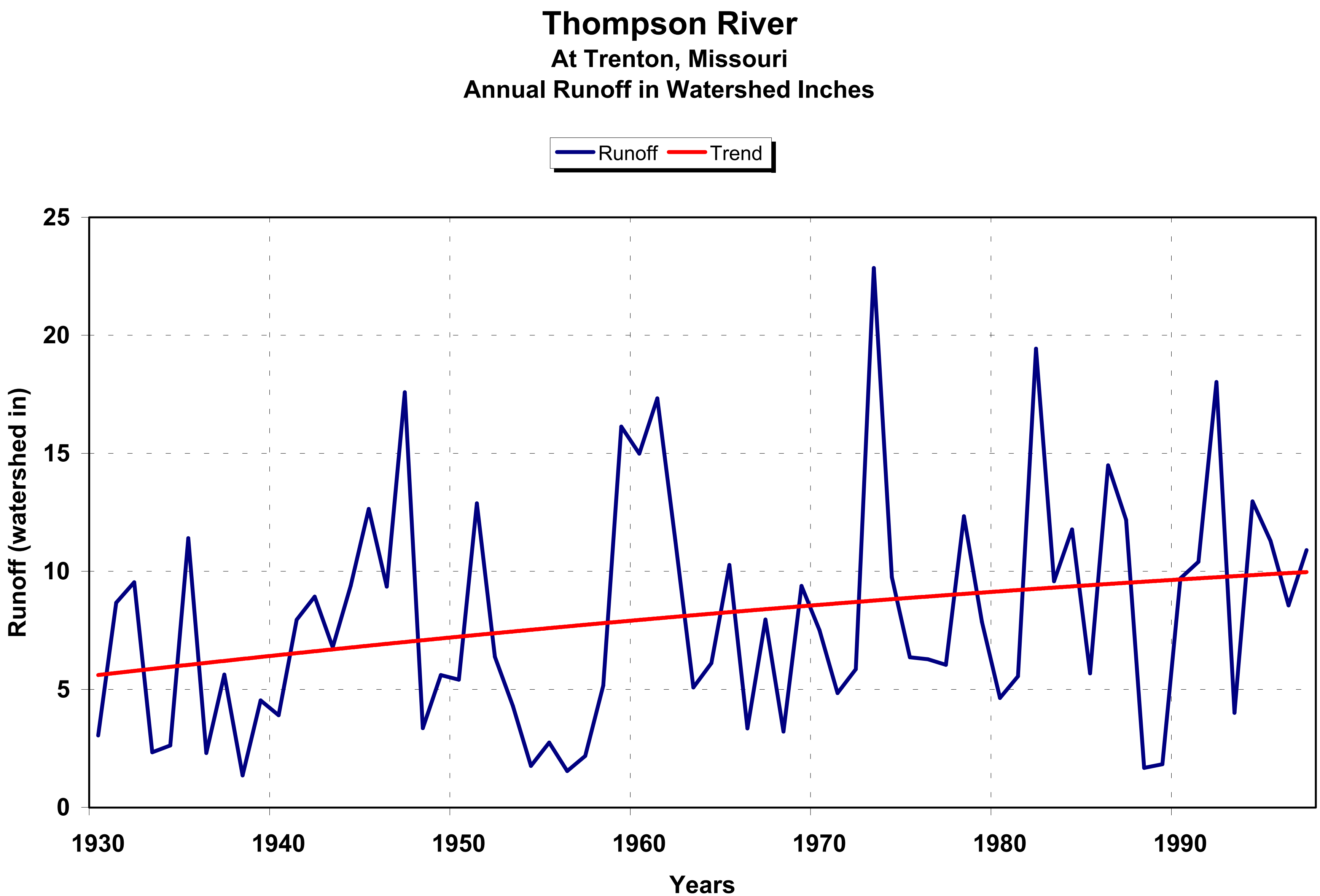

Thompson River
At Trenton, Missouri
Annual Runoff in Watershed Inches
Runoff
Trend
25
20
15
10
5
0
Runoff (watershed in)
1930
1940
1950
1960
1970
1980
1990
Years

Figure 70.3.a

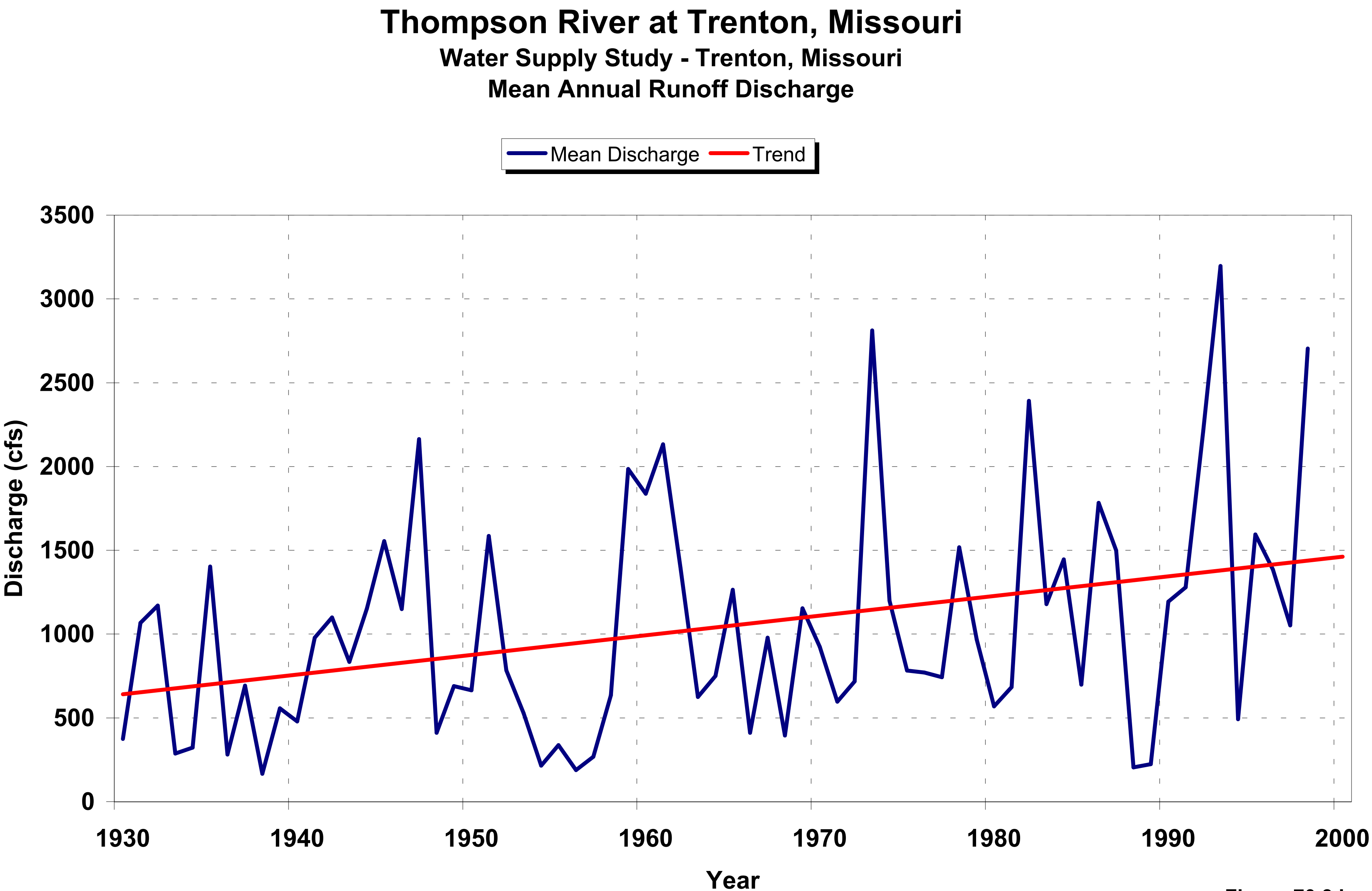

Thompson River at Trenton, Missouri
Water Supply Study - Trenton, Missouri
Mean Annual Runoff Discharge
Mean Discharge
Trend
3500
3000
2500
2000
1500
1000
500
0
Discharge (cfs)
1930
1940
1950
1960
1970
1980
1990
2000
Year

Figure 70.3.b

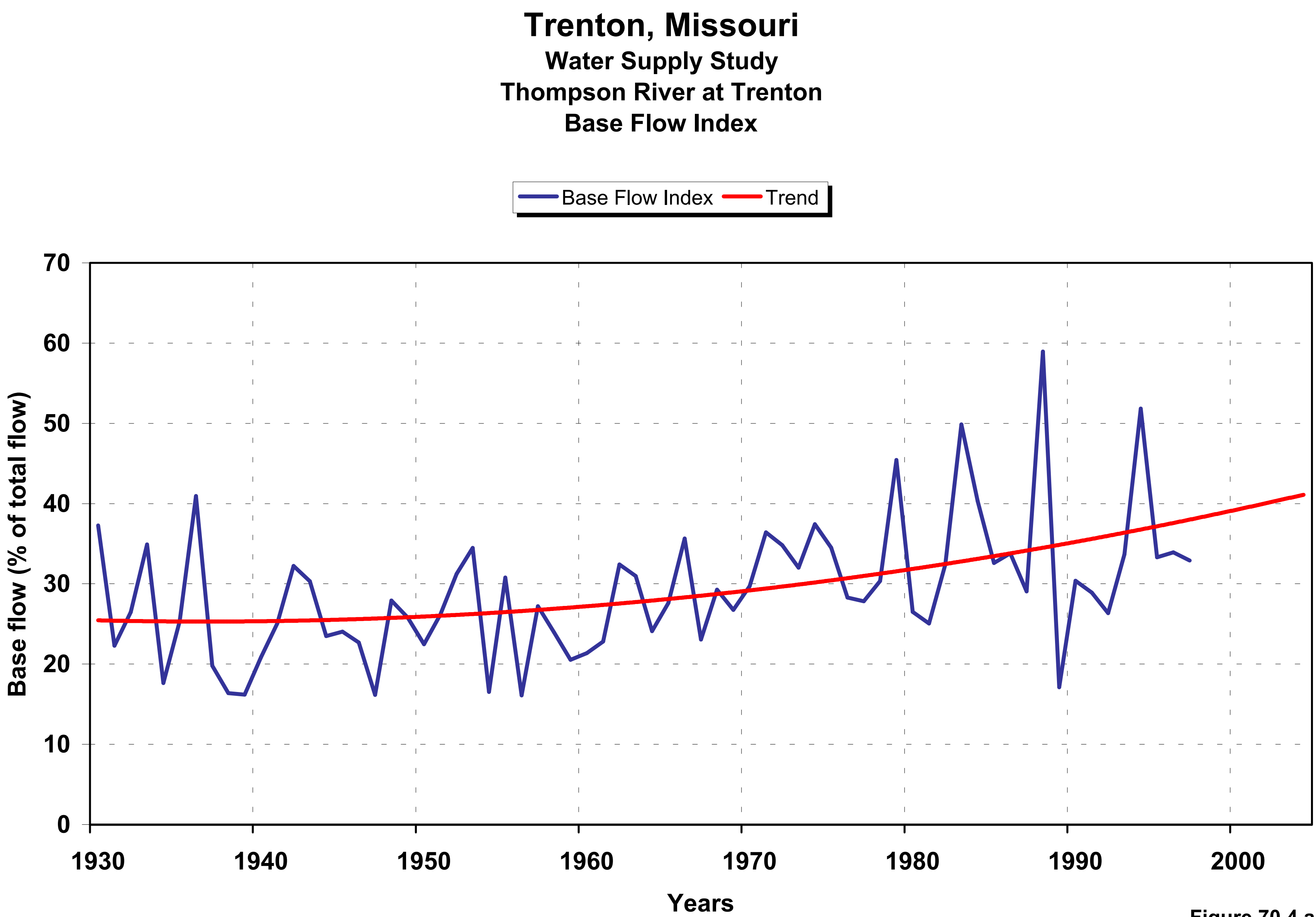

Trenton, Missouri
Water Supply Study
Thompson River at Trenton
Base Flow Index
Base Flow Index
Trend
70
60
50
40
30
20
10
0
Base flow (% of total flow)
1930
1940
1950
1960
1970
1980
1990
2000
Years

Figure 70.4.a

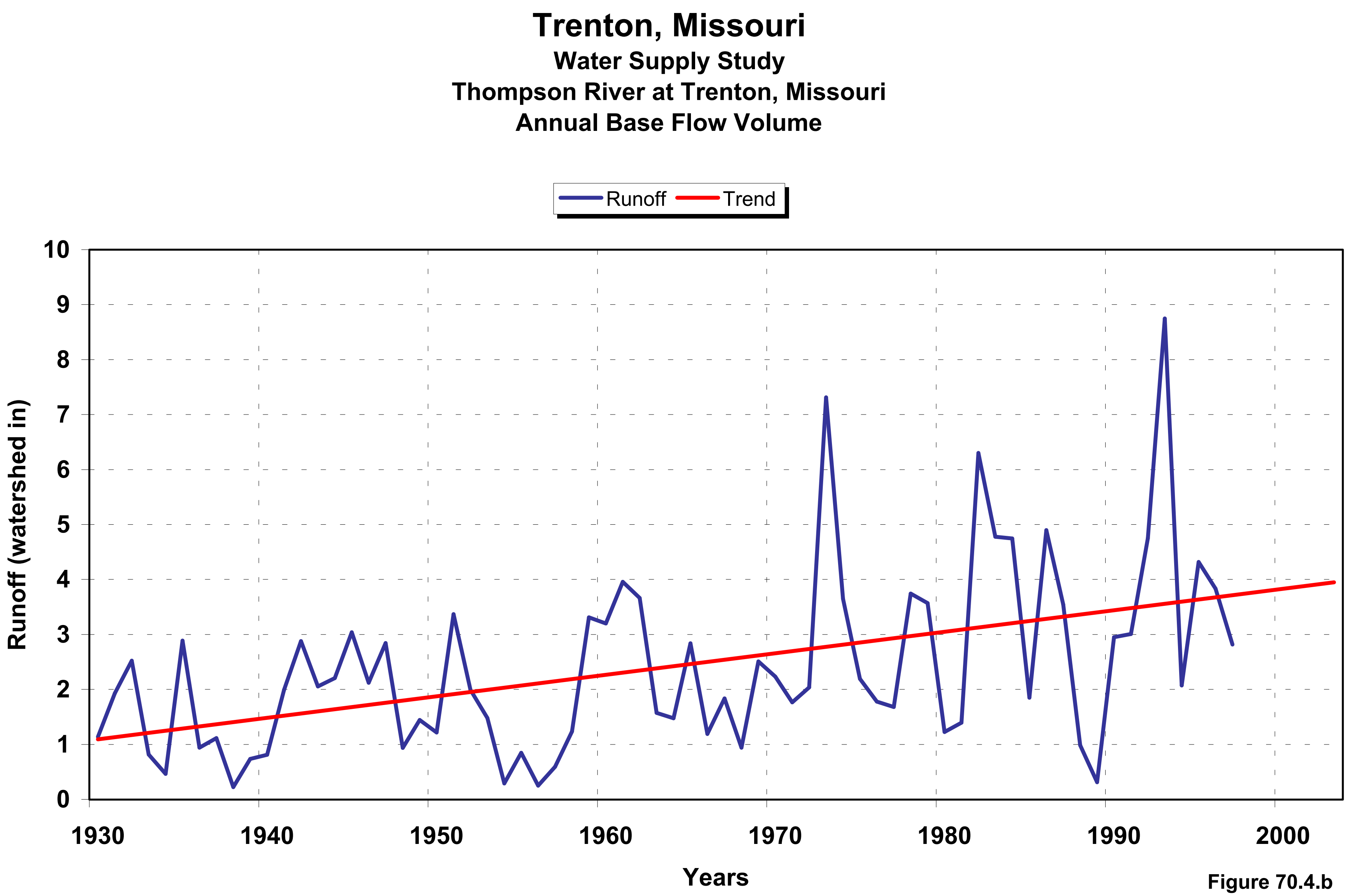

Trenton, Missouri
Water Supply Study
Thompson River at Trenton, Missouri
Annual Base Flow Volume
Runoff
Trend
Runoff (watershed in)
0
1
2
3
4
5
6
7
8
9
10
1930
1940
1950
1960
1970
1980
1990
2000
Years

Figure 70.4.b

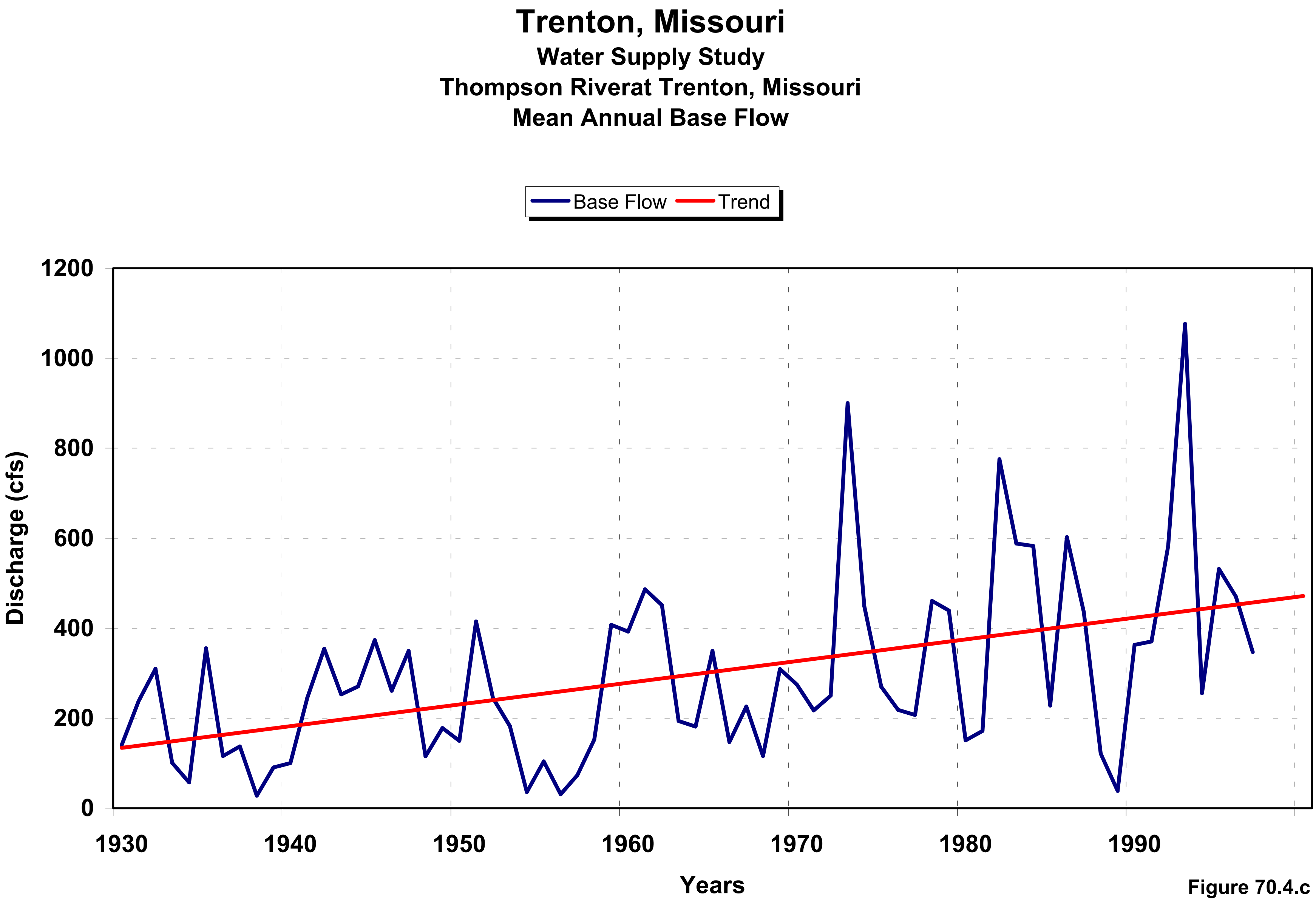

Trenton, Missouri
Water Supply Study
Thompson Riverat Trenton, Missouri
Mean Annual Base Flow
Base Flow
Trend
1200
1000
800
600
400
200
0
Discharge (cfs)
1930
1940
1950
1960
1970
1980
1990
Years

Figure 70.4.c

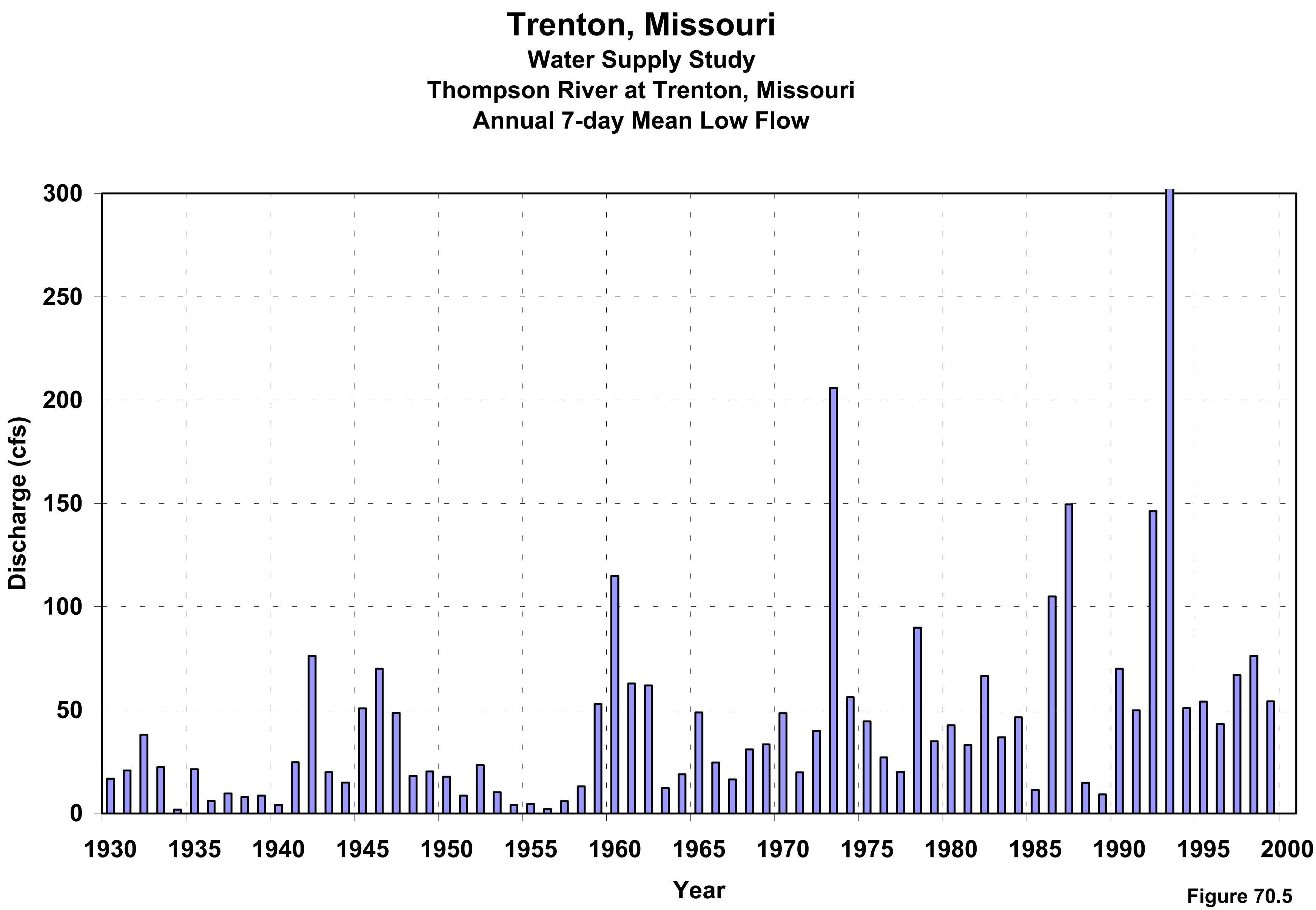

Trenton, Missouri
Water Supply Study
Thompson River at Trenton, Missouri
Annual 7-day Mean Low Flow
Discharge (cfs)
0
50
100
150
200
250
300
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year

Figure 70.5

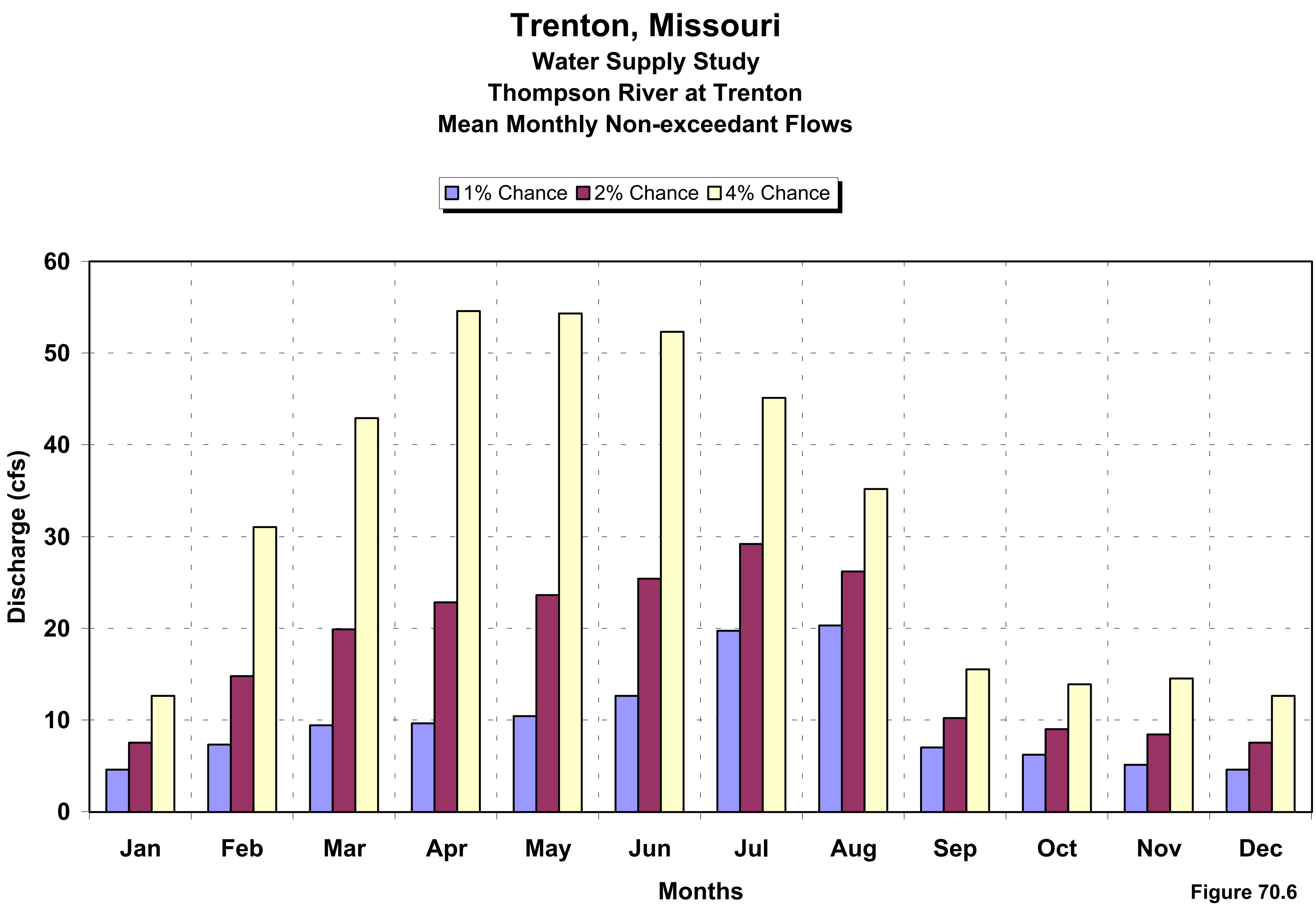

Trenton, Missouri
Water Supply Study
Thompson River at Trenton
Mean Monthly Non-exceedant Flows
1% Chance
2% Chance
4% Chance
Discharge (cfs)
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 70.6

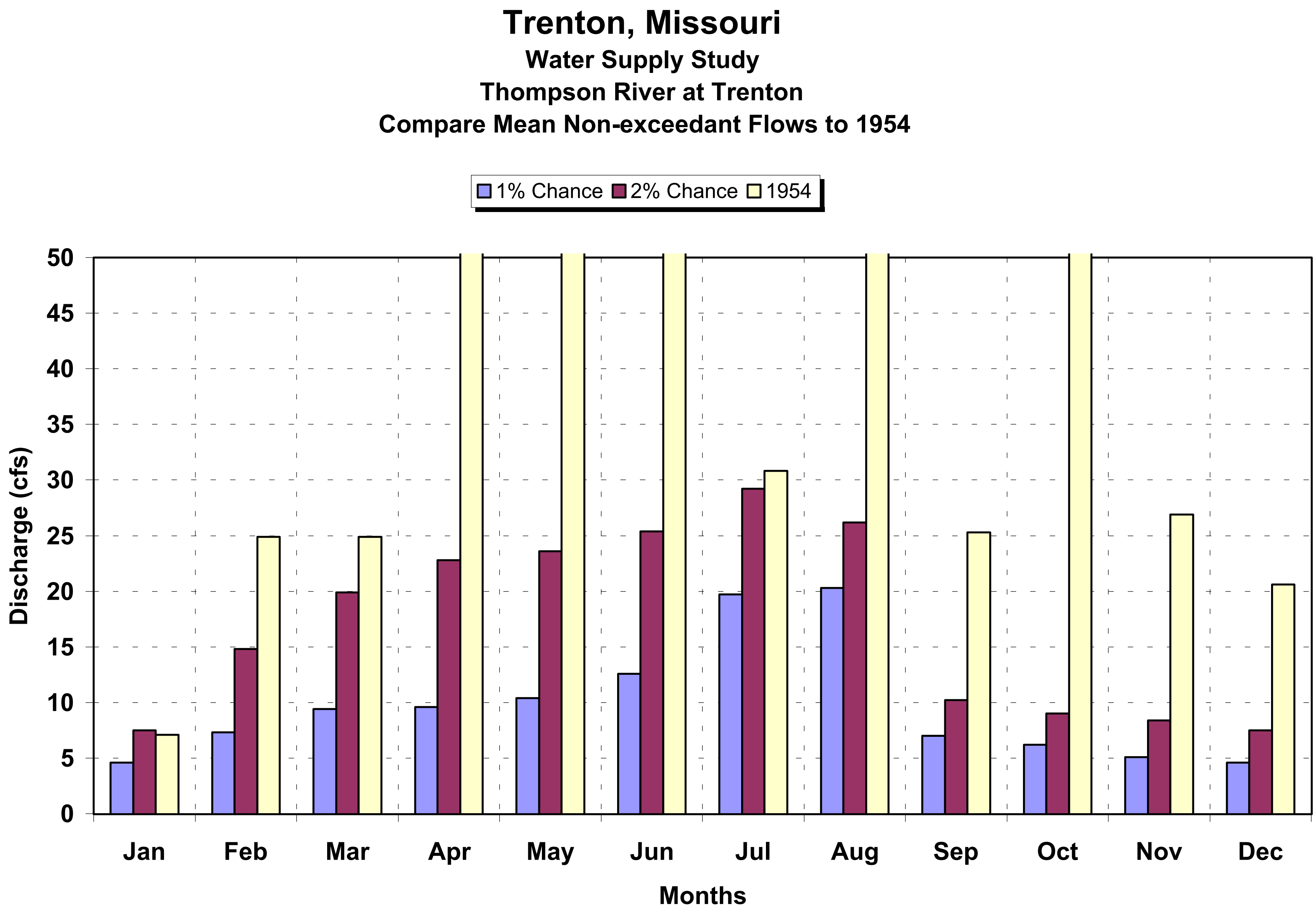

Trenton, Missouri
Water Supply Study
Thompson River at Trenton
Compare Mean Non-exceedant Flows to 1954
1% Chance
2% Chance
1954
Discharge (cfs)
0
5
10
15
20
25
30
35
40
45
50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Figure 70.7.a

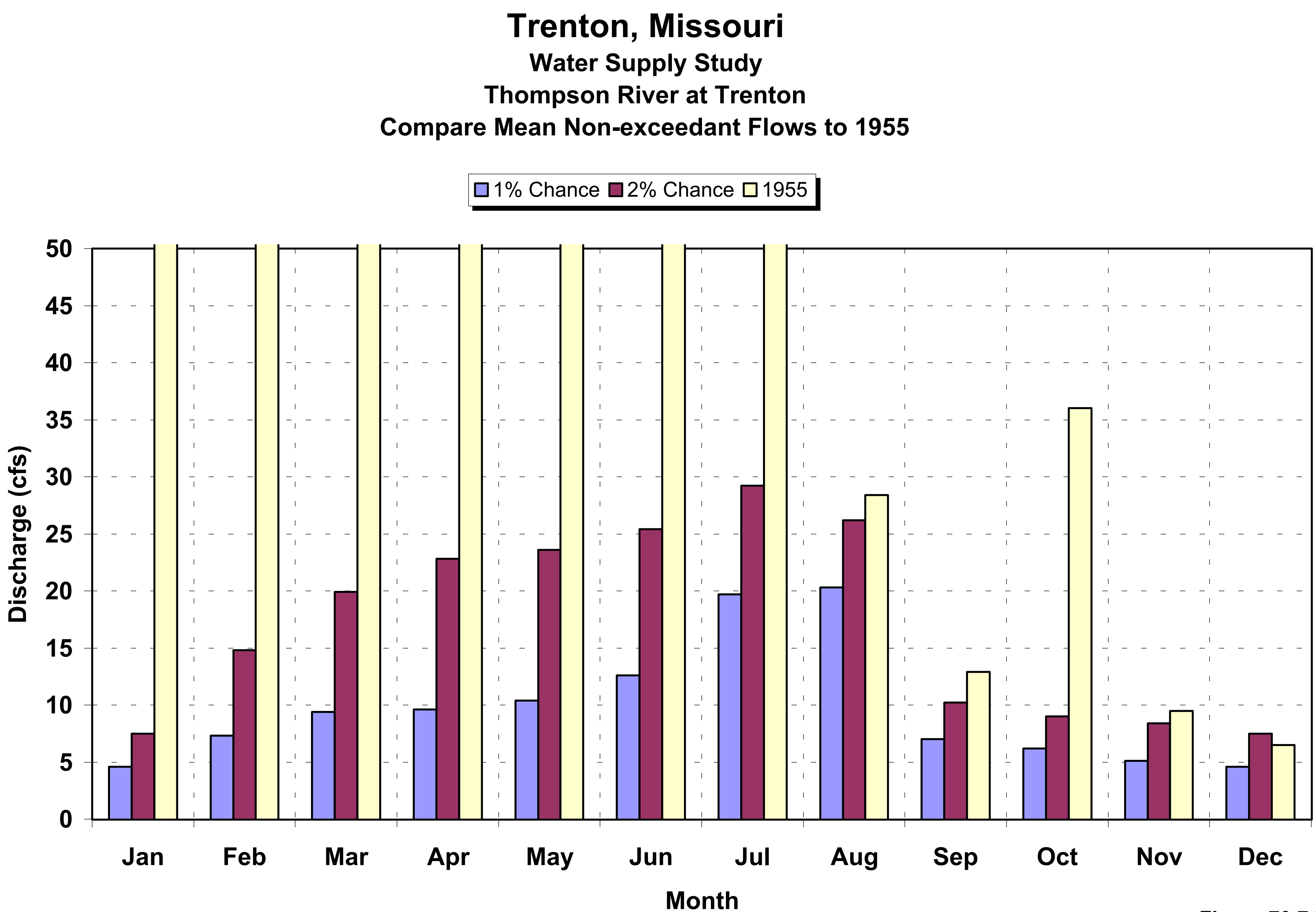

Trenton, Missouri
Water Supply Study
Thompson River at Trenton
Compare Mean Non-exceedant Flows to 1955
1% Chance
2% Chance
1955
Discharge (cfs)
0
5
10
15
20
25
30
35
40
45
50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 70.7.b

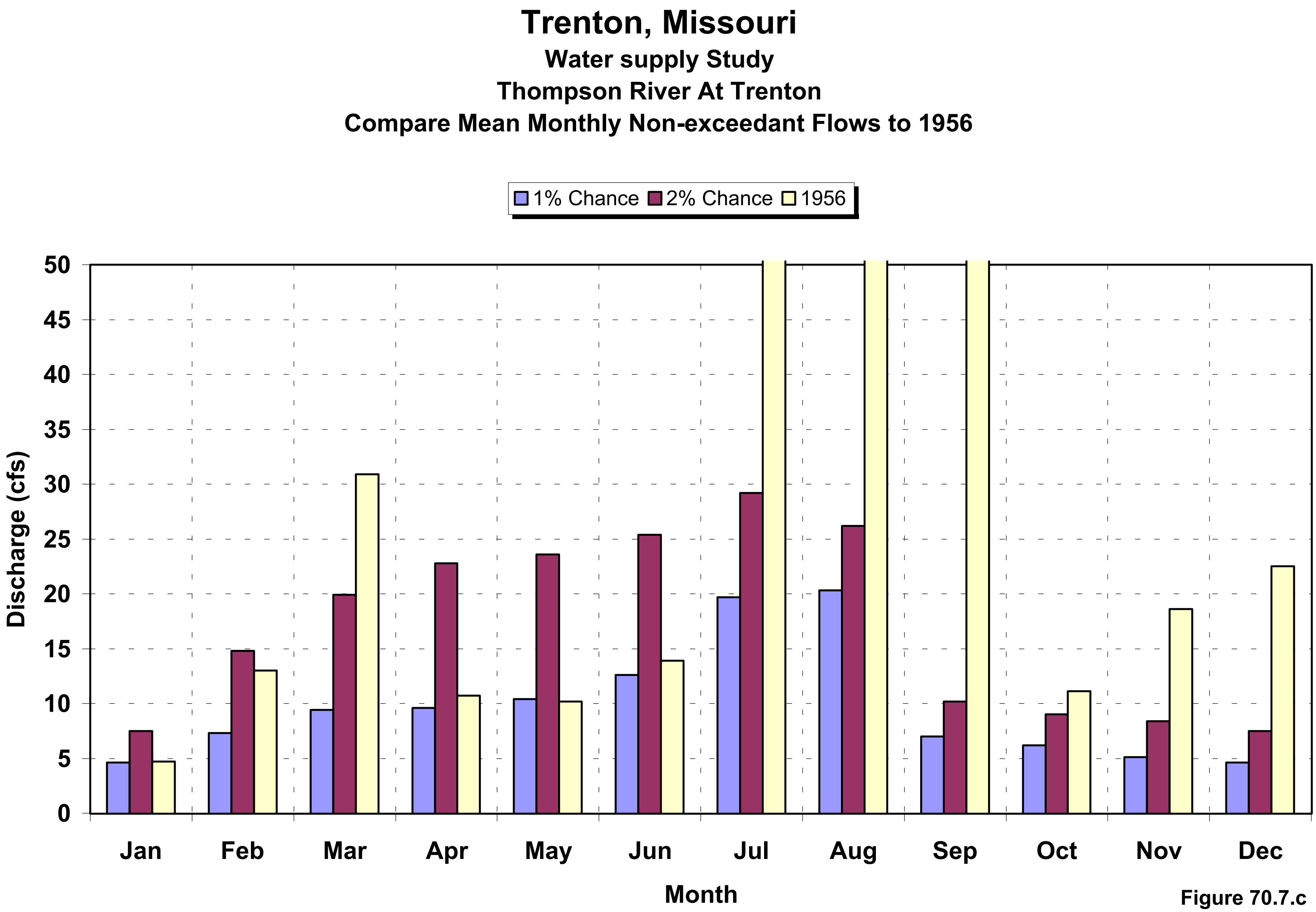

Trenton, Missouri
Water supply Study
Thompson River At Trenton
Compare Mean Monthly Non-exceedant Flows to 1956
1% Chance
2% Chance
1956
50
45
40
35
30
25
20
15
10
5
0
Discharge (cfs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 70.7.c

Trenton, Missouri
Water Supply Study
Thompson River at Trenton, Missouri
Compare Mean Monthly Non-exceedant Flows to 1957

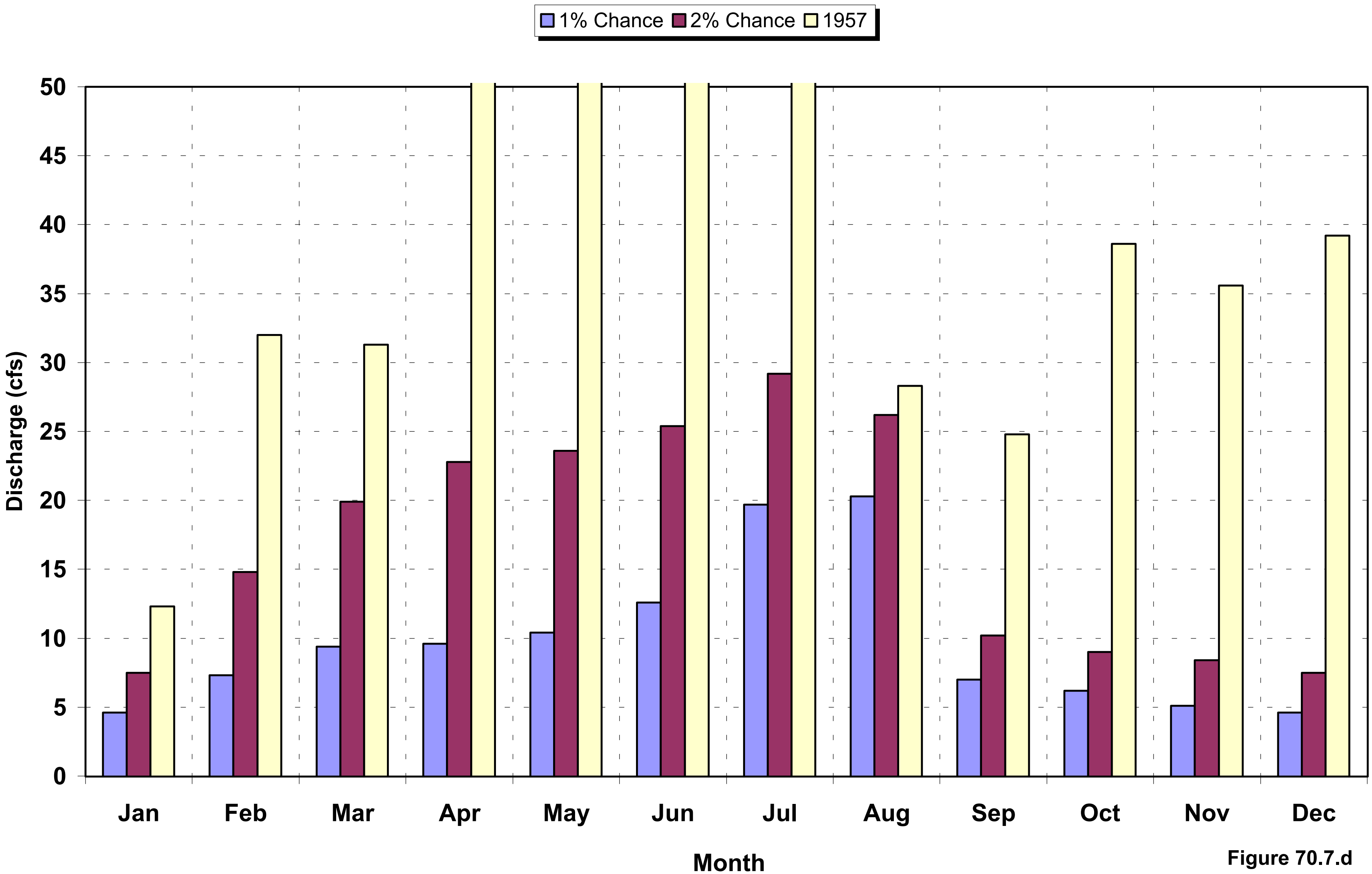


Figure 70.7.d

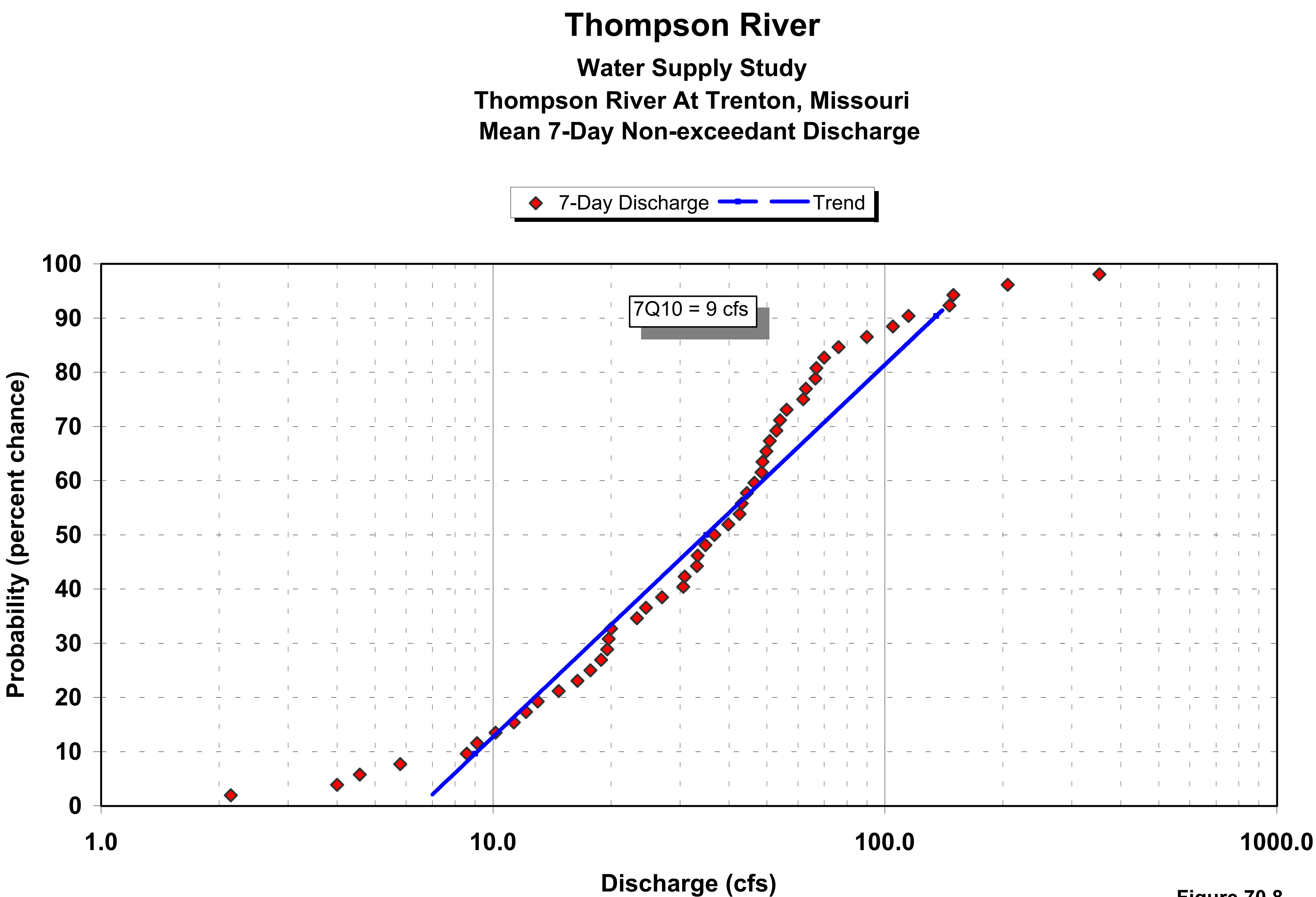
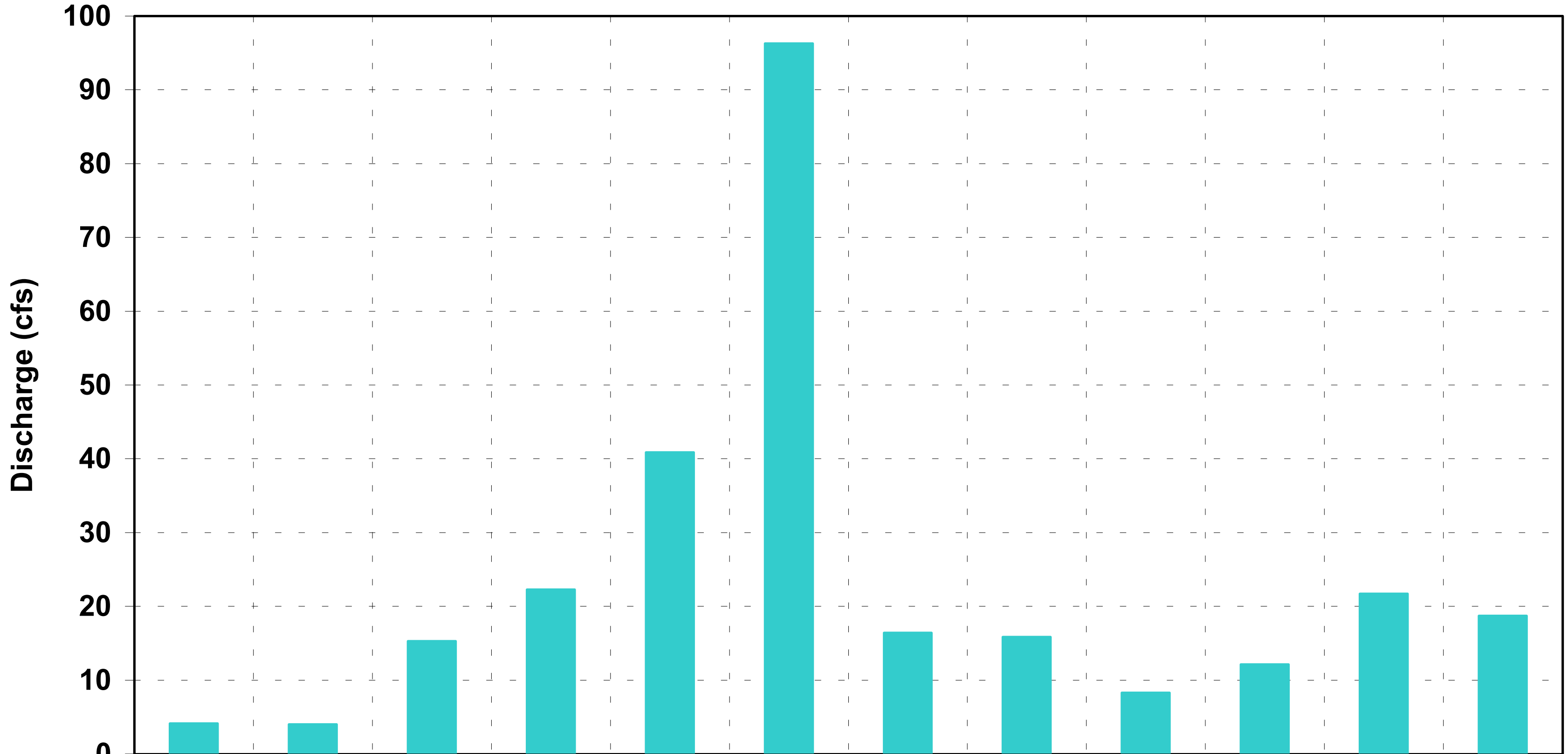

Thompson River
Water Supply Study
Thompson River At Trenton, Missouri
Mean 7-Day Non-exceedant Discharge
7-Day Discharge
Trend
7Q10 = 9 cfs
Probability (percent chance)
100
90
80
70
60
50
40
30
20
10
0
1.0
10.0
100.0
1000.0
Discharge (cfs)

Figure 70.8

Trenton Missouri
Water Supply Study
Thompson RiverAt Trenton, Missouri
Mean 7-day low flow for 1954

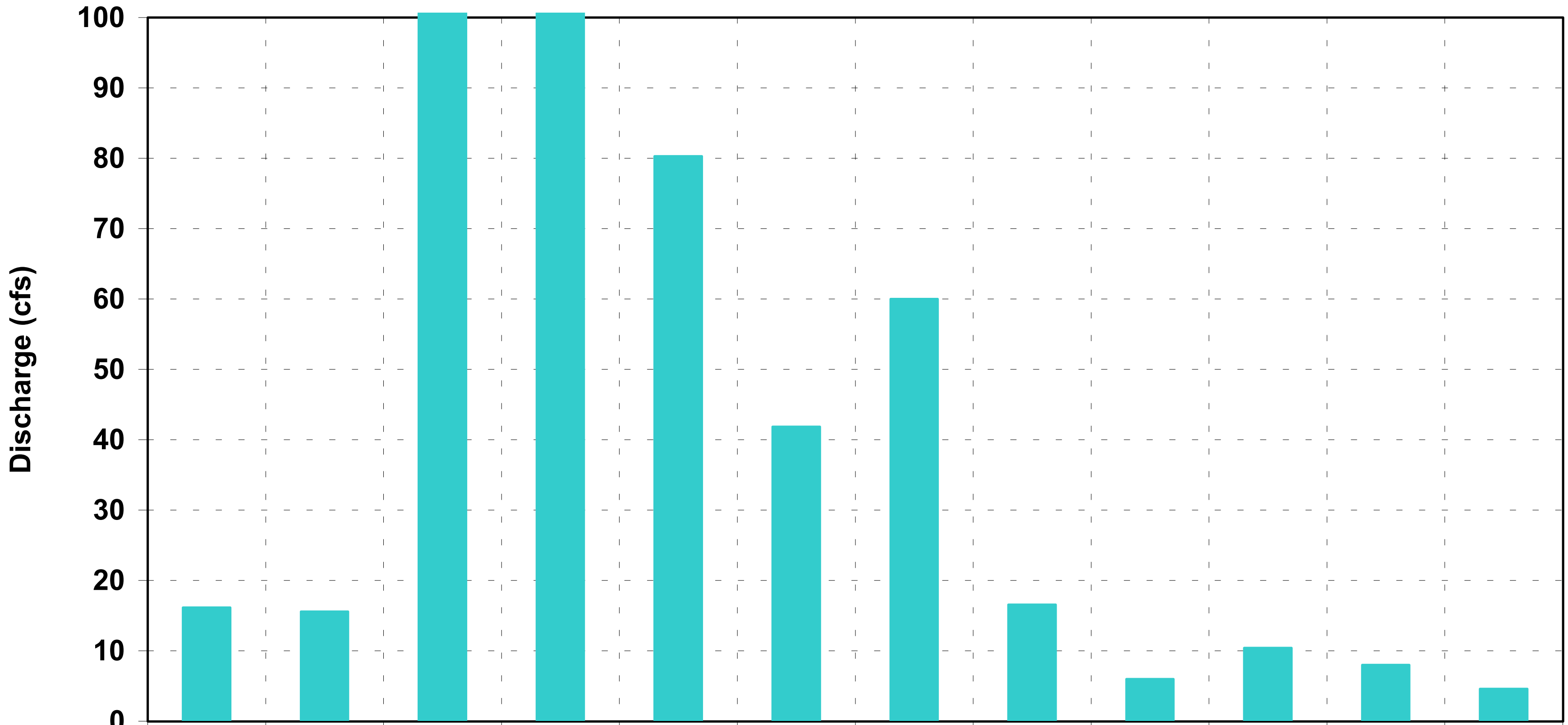


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	sep	Oct	Nov	Dec
1954	4	4	15	22	41	96	16	16	8	12	22	19

Months

Figure 70.9.a

Trenton Missouri
Water Supply Study
Thompson RiverAt Trenton, Missouri
Mean 7-day low flow for 1955



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	sep	Oct	Nov	Dec
1955	16	16	262	143	80	42	60	17	6	10	8	5

Months

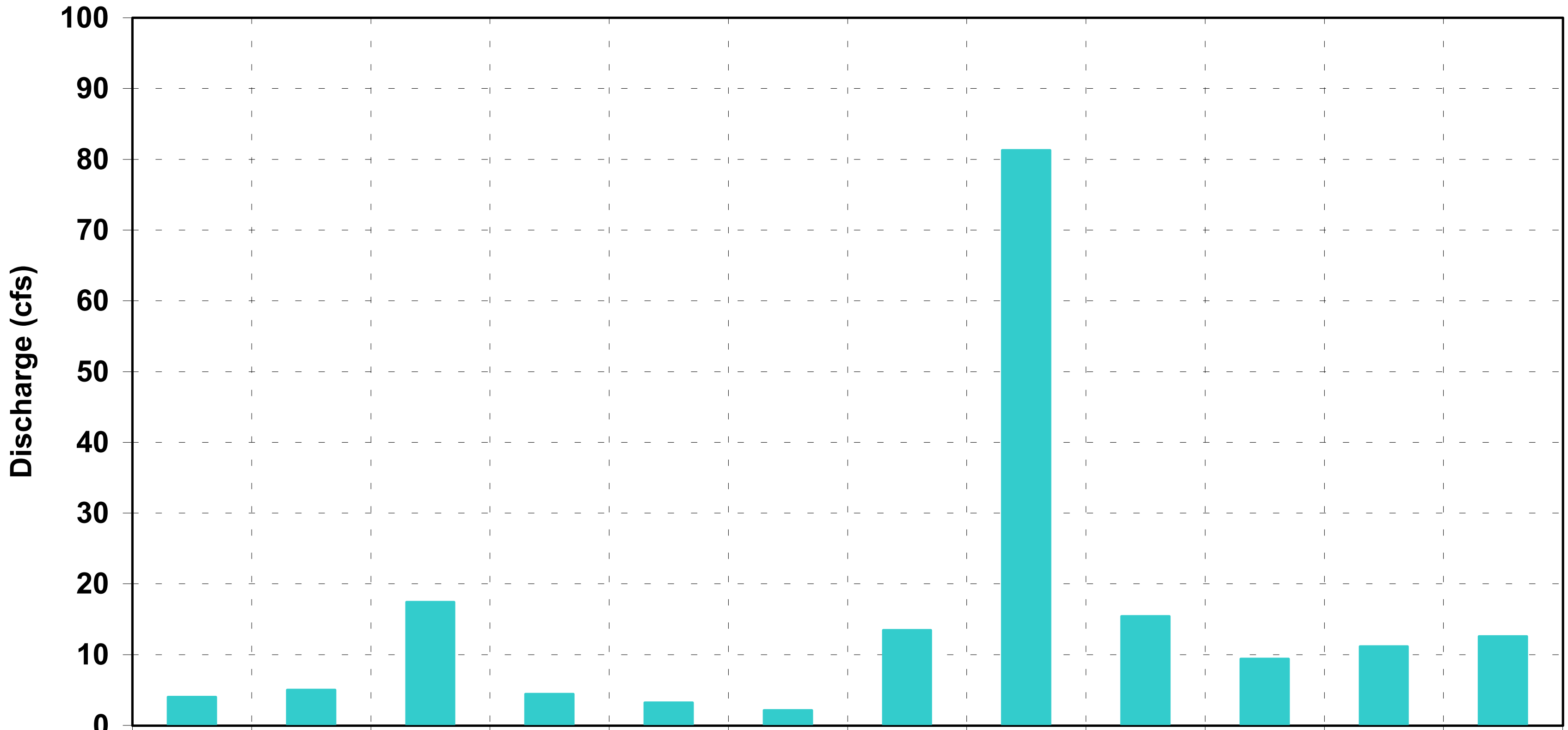
Figure 70.9.b

Trenton Missouri

Water Supply Study

Thompson RiverAt Trenton, Missouri

Mean 7-day low flow for 1956



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	sep	Oct	Nov	Dec
1956	4	5	17	4	3	2	13	81	15	9	11	13

Months

Figure 70.9.c

Thompson River

Water Supply Study
At Trenton, Missouri
Mean 7-day Low Flow by Months in 1957

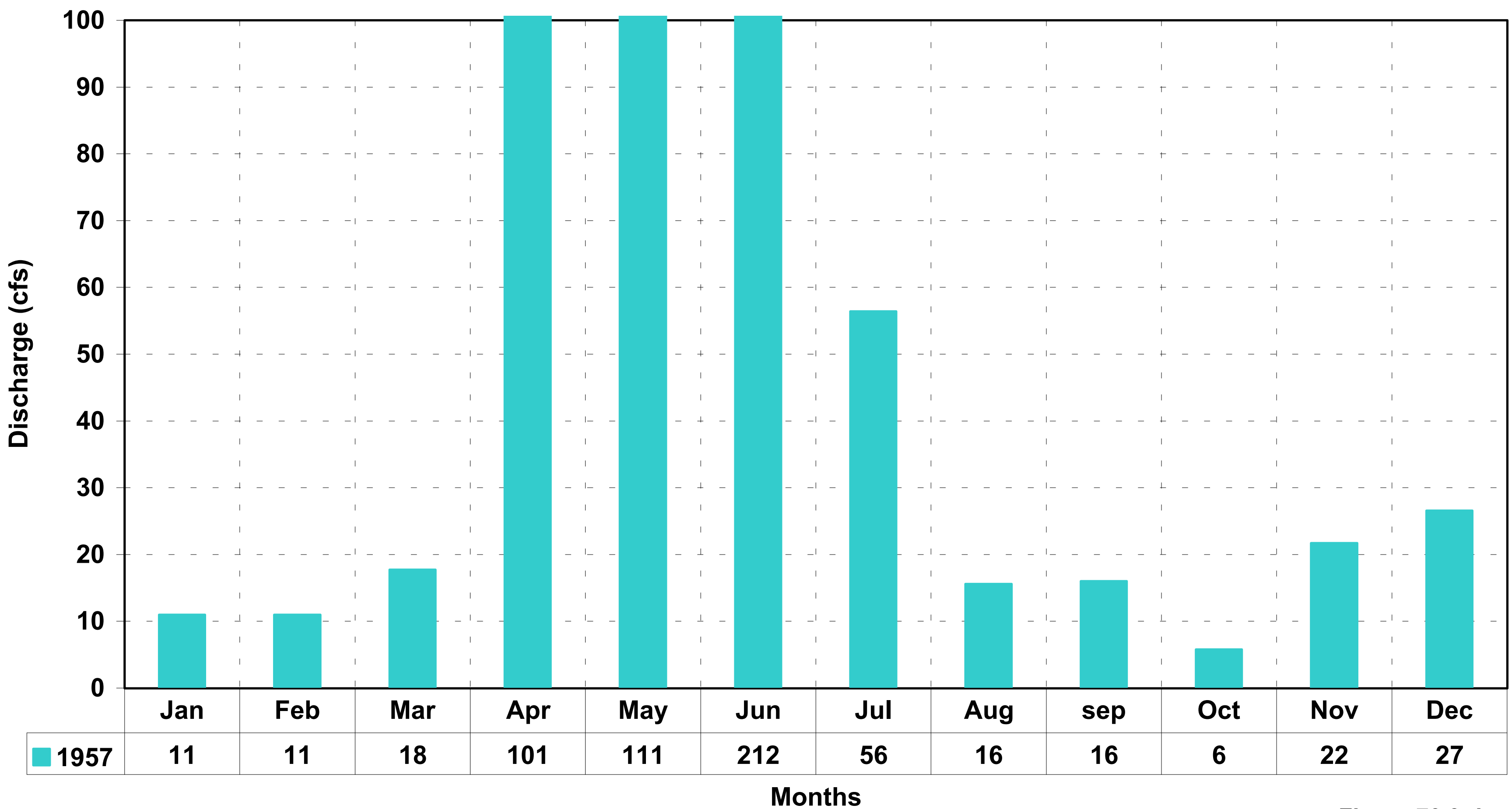
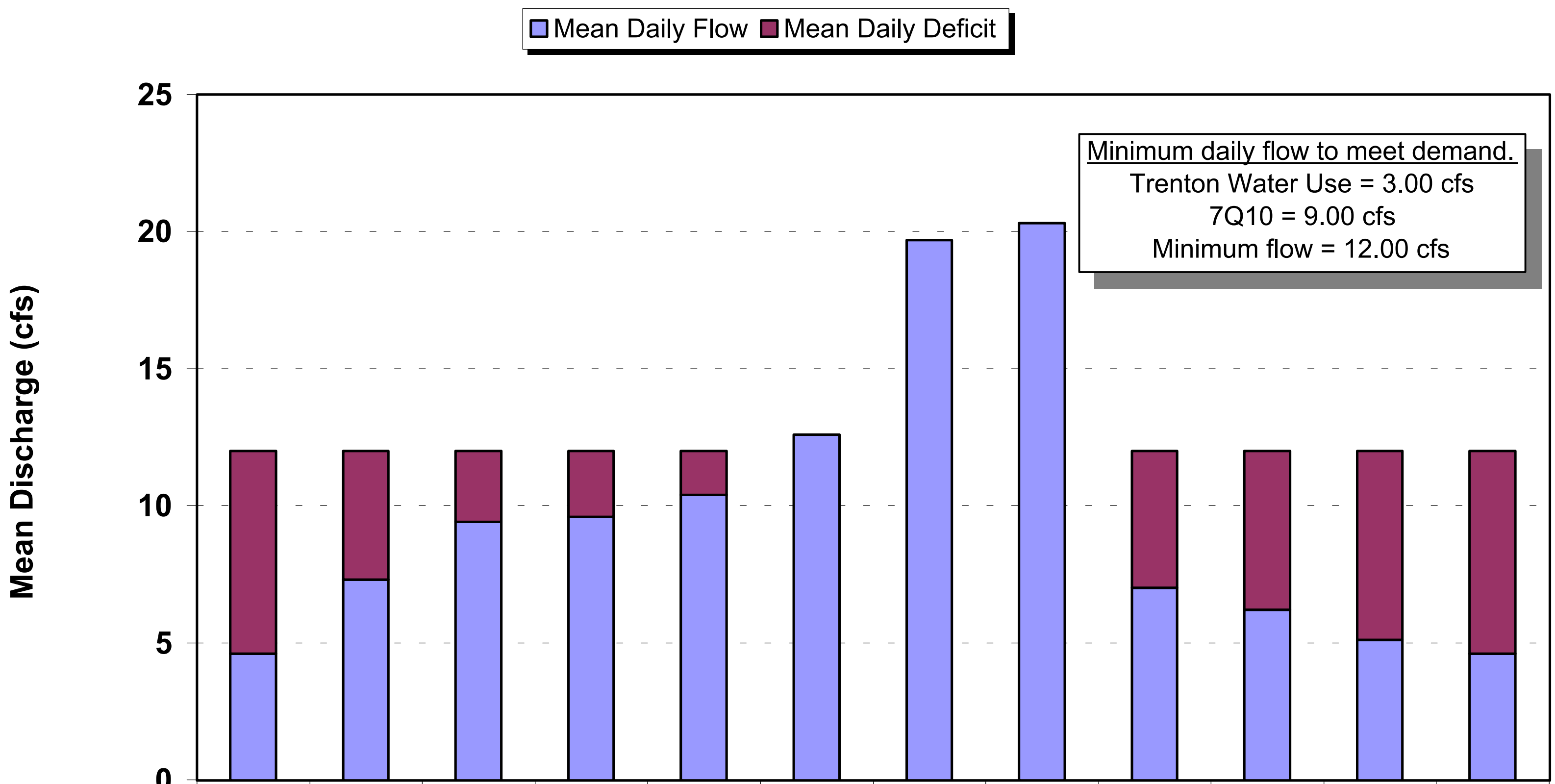


Figure 70.9.d

Trenton, Missouri
Water Supply Study
Thompson River at Trenton
1% chance Non-exceedant Flow or 1 Year in 100

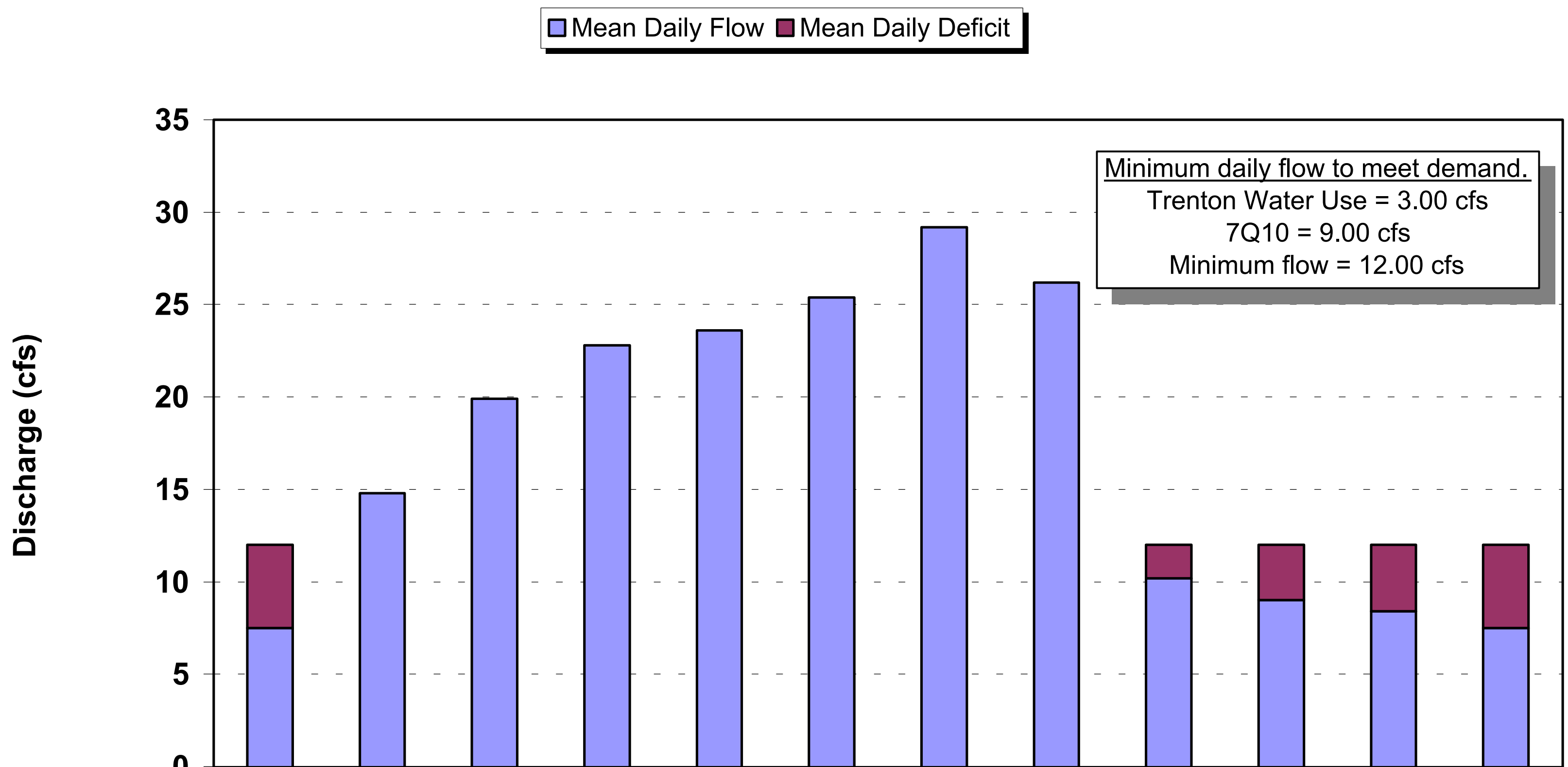


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Daily Deficit	7.4	4.7	2.6	2.4	1.6	0	0	0	5	5.8	6.9	7.4
Mean Daily Flow	4.6	7.3	9.4	9.6	10.4	12.6	19.7	20.3	7	6.2	5.1	4.6

Month

Figure 70.10.a

Trenton, Missouri
Water Supply Study
Thompson River at Trenton
2% chance Non-exceedant Flow or 1 Year in 50



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Daily Deficit	4.5	0	0	0	0	0	0	0	1.8	3	3.6	4.5
Mean Daily Flow	7.5	14.8	19.9	22.8	23.6	25.4	29.2	26.2	10.2	9	8.4	7.5

Month

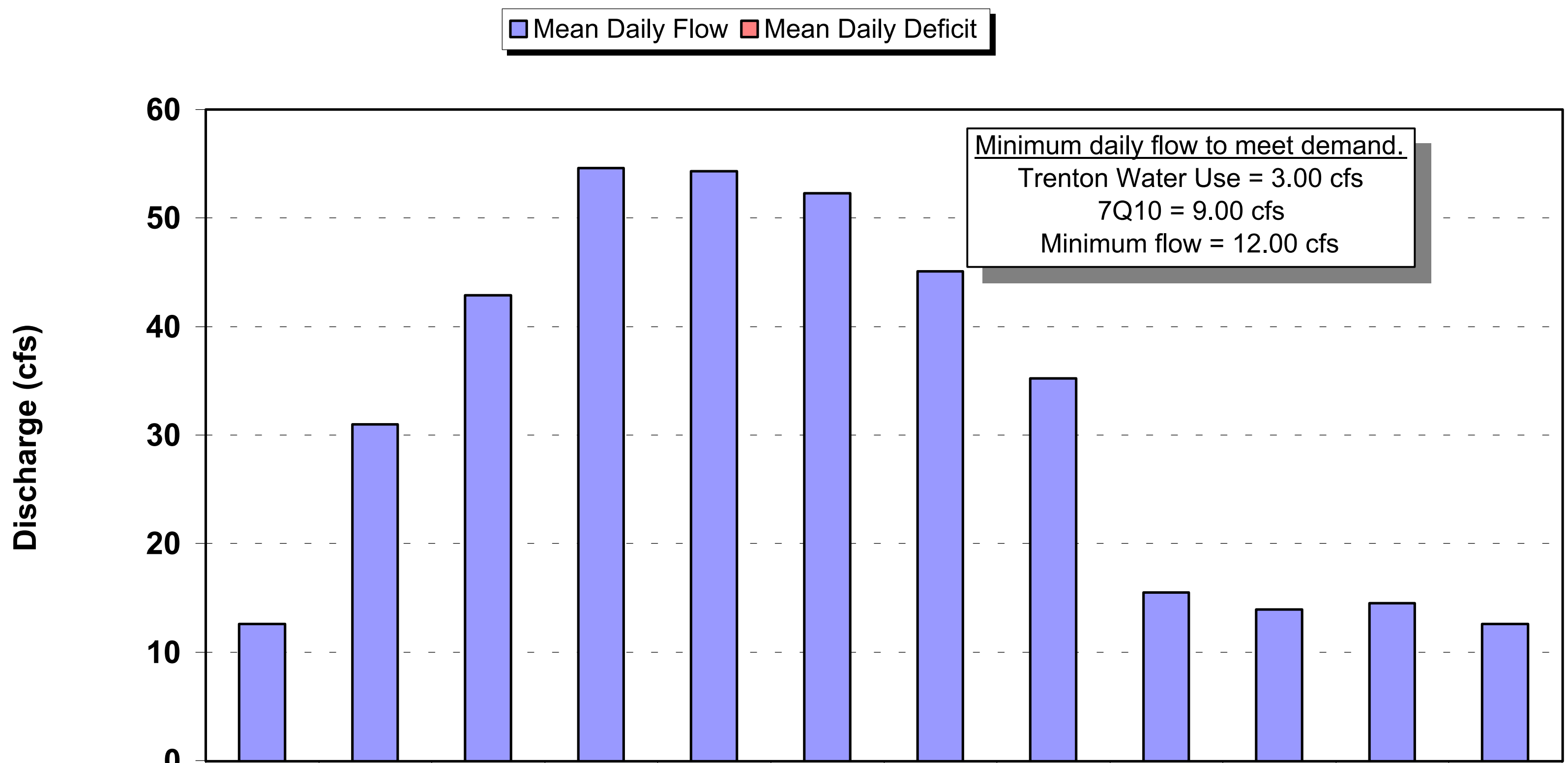
Figure 70.10.b

Trenton, Missouri

Water Supply Study

Thompson River at Trenton

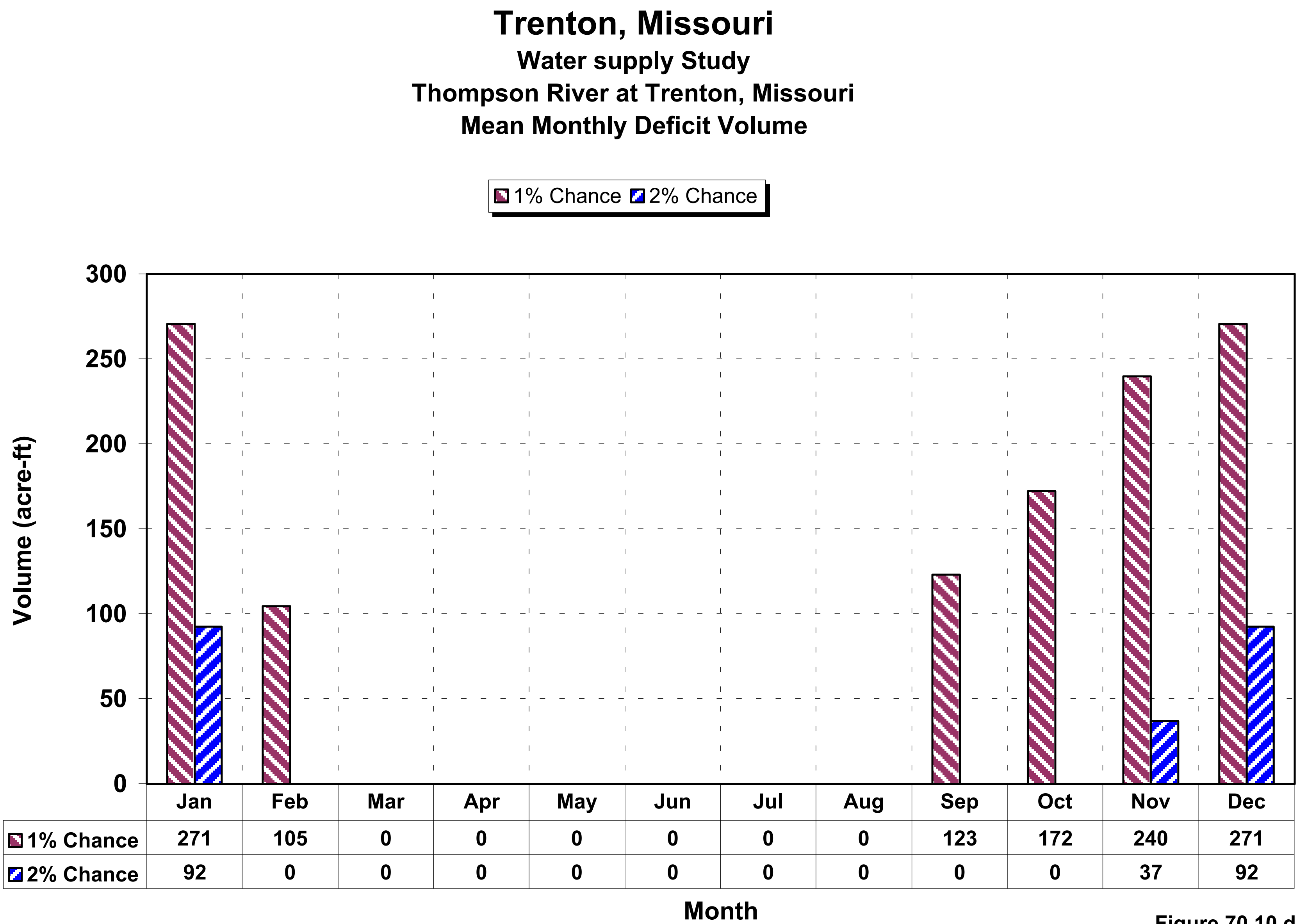
4% chance Non-exceedant Flow or 1 Year in 25



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Daily Deficit	0	0	0	0	0	0	0	0	0	0	0	0
Mean Daily Flow	12.6	31	42.9	54.6	54.3	52.3	45.1	35.2	15.5	13.9	14.5	12.6

Month

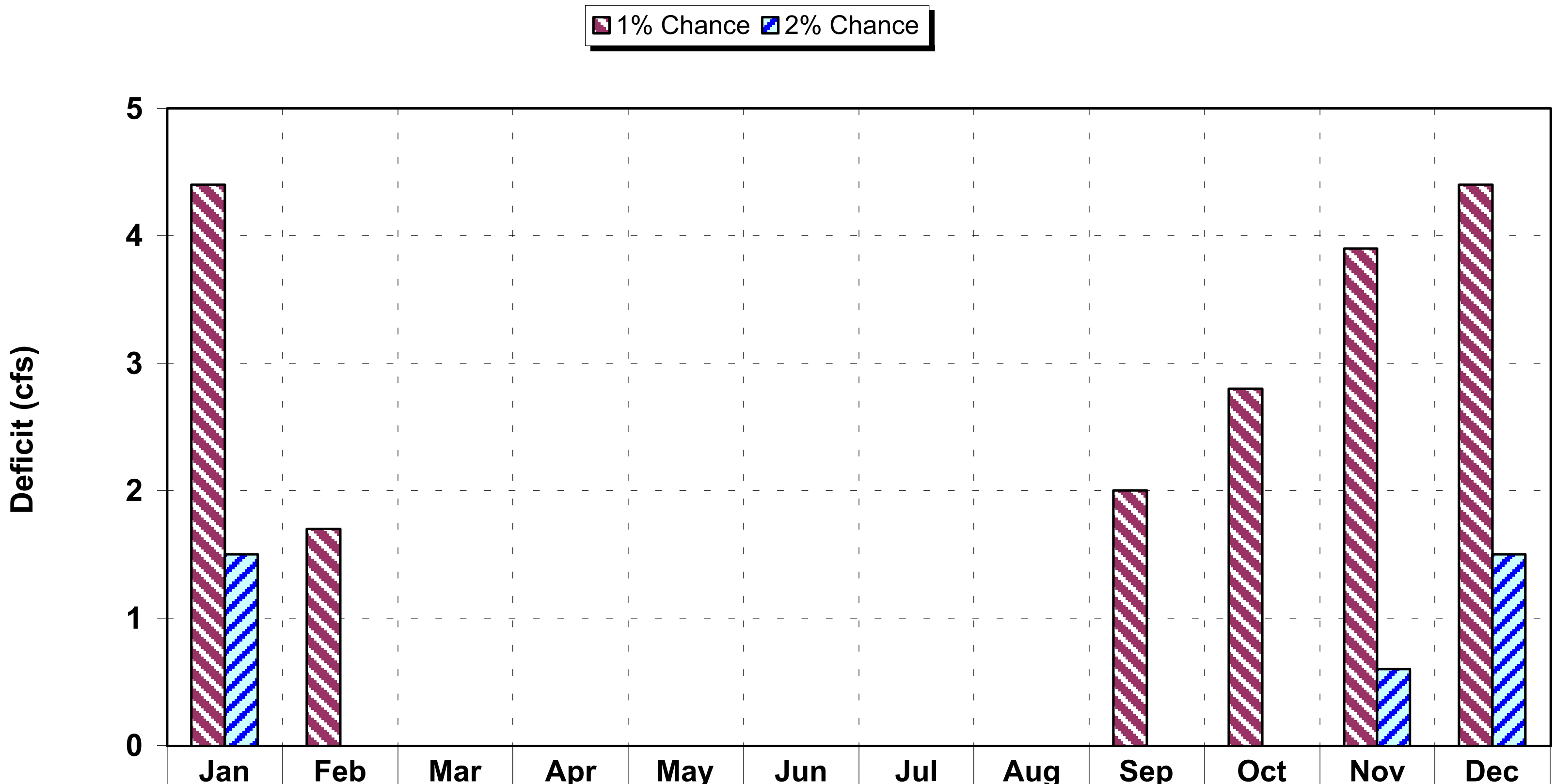
Figure 70.10.c



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1% Chance	271	105	0	0	0	0	0	0	123	172	240	271
2% Chance	92	0	0	0	0	0	0	0	0	0	37	92

Figure 70.10.d

Trenton, Missouri
Water supply Study
Thompson River at Trenton, Missouri
Mean Monthly Deficit Discharge



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1% Chance	4.4	1.7	0	0	0	0	0	0	2	2.8	3.9	4.4
2% Chance	1.5	0	0	0	0	0	0	0	0	0	0.6	1.5

Month

Figure 70.10.e

Water Supply Projections

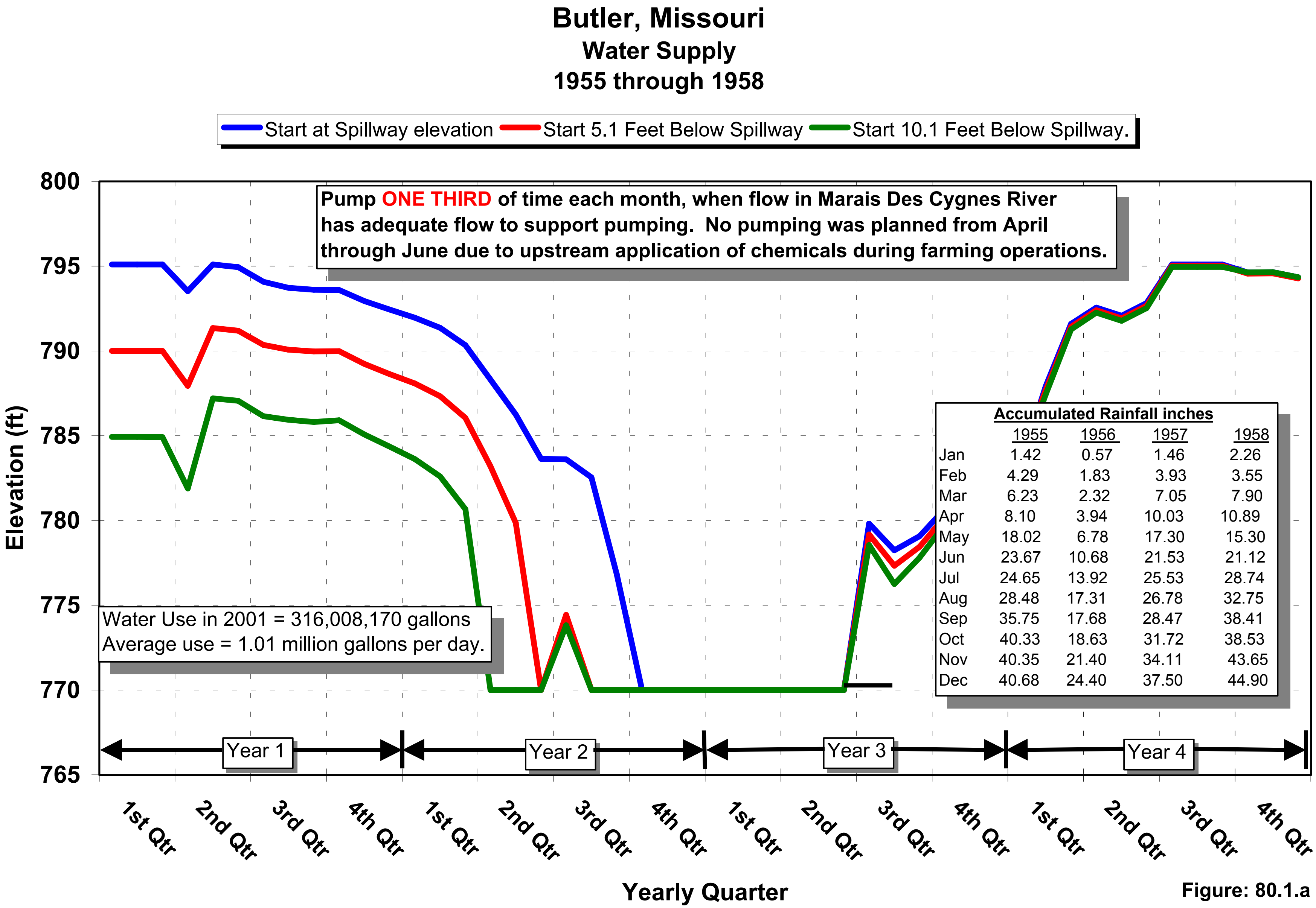
Introduction

Five of the lakes were selected for installation of staff gauges for monitoring the volume of water in the lakes. Lakes with staff gauges are Butler, Hamilton, Harrison County Public Water Supply District No. 1, Marceline and Monroe City. The volume in each lake is determined by reading the elevation on the staff gauge and looking at the elevation-storage plot to determine the existing volume of water in the lake. With the storage and rainfall history, an estimate of future demands on the system can be made using one of the two recent historical drought periods of 1955 through 1957 and 1988 through 1990. Recent average daily municipal water demands were used to develop the charts. Year 2000 was used to develop the Marceline and Monroe City charts. Year 2001 was used for the other 3 cities. The year was selected based on the highest daily demand. By use of these charts and reading the staff gauges, an estimate of remaining water supply may be made for planning future water needs.

Analysis for development for staff gauge studies

Staff gauges were installed for monitoring the volume of water in each of the five lakes selected and were used to project an estimate of future water availability for developing a plan to extend the water supply to get through the drought cycle.

Two drought periods are presented for comparing to a drought condition. The most recent period extended from 1988 through 1989. The most severe extended from 1955 through 1958. The RESOP program was used to estimate the effects of each drought period. Three RESOP runs were made on each reservoir for both dry periods. One beginning at full pool, the second beginning five feet below the spillway and the third run beginning ten feet below the spillway. Monthly accumulated rainfall for each of the dry periods are presented so that comparisons can be made for a current drought and the historical dry period.



	1955	1956	1957	1958
Jan	1.42	0.57	1.46	2.26
Feb	4.29	1.83	3.93	3.55
Mar	6.23	2.32	7.05	7.90
Apr	8.10	3.94	10.03	10.89
May	18.02	6.78	17.30	15.30
Jun	23.67	10.68	21.53	21.12
Jul	24.65	13.92	25.53	28.74
Aug	28.48	17.31	26.78	32.75
Sep	35.75	17.68	28.47	38.41
Oct	40.33	18.63	31.72	38.53
Nov	40.35	21.40	34.11	43.65
Dec	40.68	24.40	37.50	44.90

Figure: 80.1.a

Butler, Missouri
Water Supply
1988 through 1990

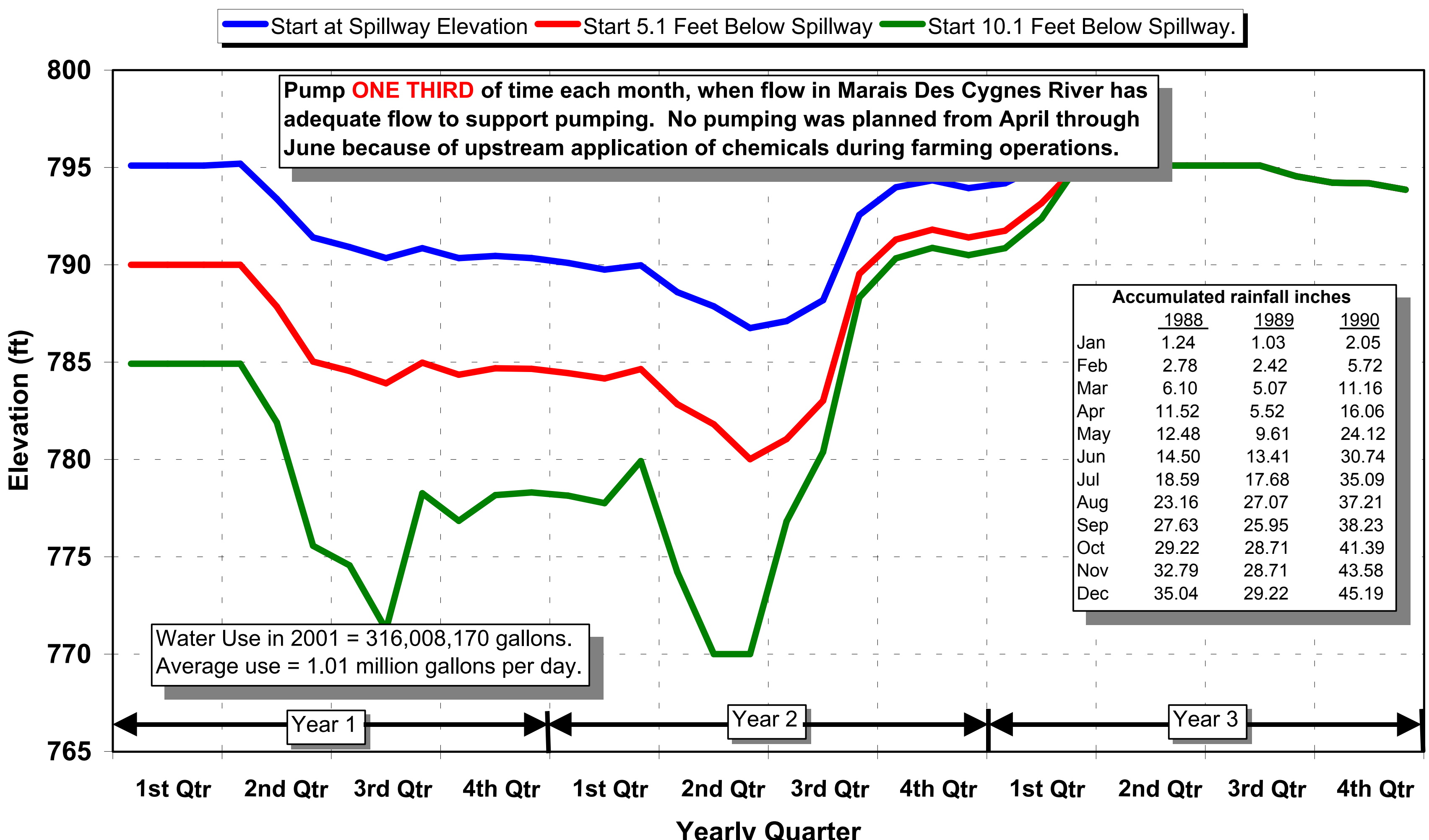
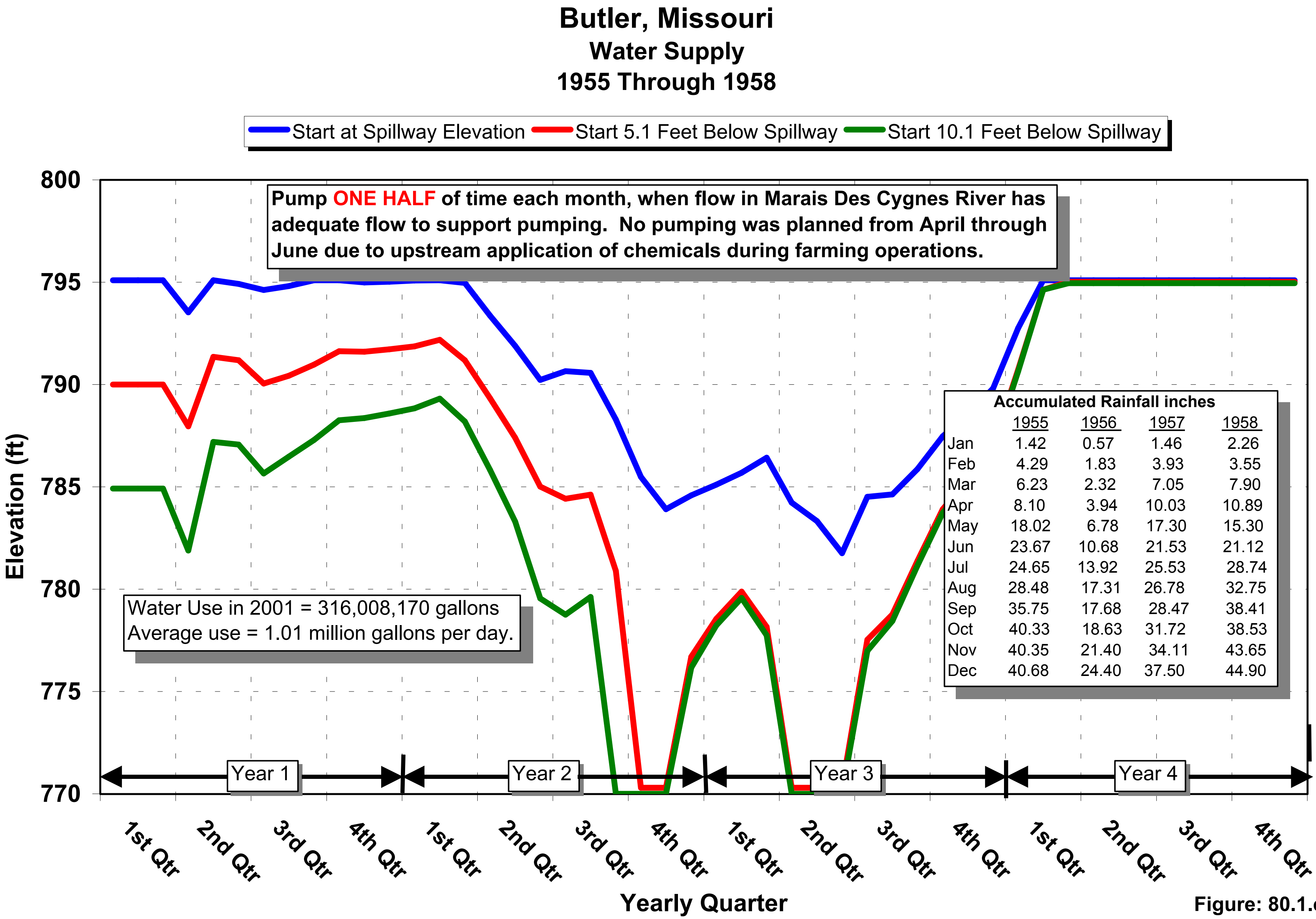


Figure: 80.1.b



	1955	1956	1957	1958
Jan	1.42	0.57	1.46	2.26
Feb	4.29	1.83	3.93	3.55
Mar	6.23	2.32	7.05	7.90
Apr	8.10	3.94	10.03	10.89
May	18.02	6.78	17.30	15.30
Jun	23.67	10.68	21.53	21.12
Jul	24.65	13.92	25.53	28.74
Aug	28.48	17.31	26.78	32.75
Sep	35.75	17.68	28.47	38.41
Oct	40.33	18.63	31.72	38.53
Nov	40.35	21.40	34.11	43.65
Dec	40.68	24.40	37.50	44.90

Figure: 80.1.c

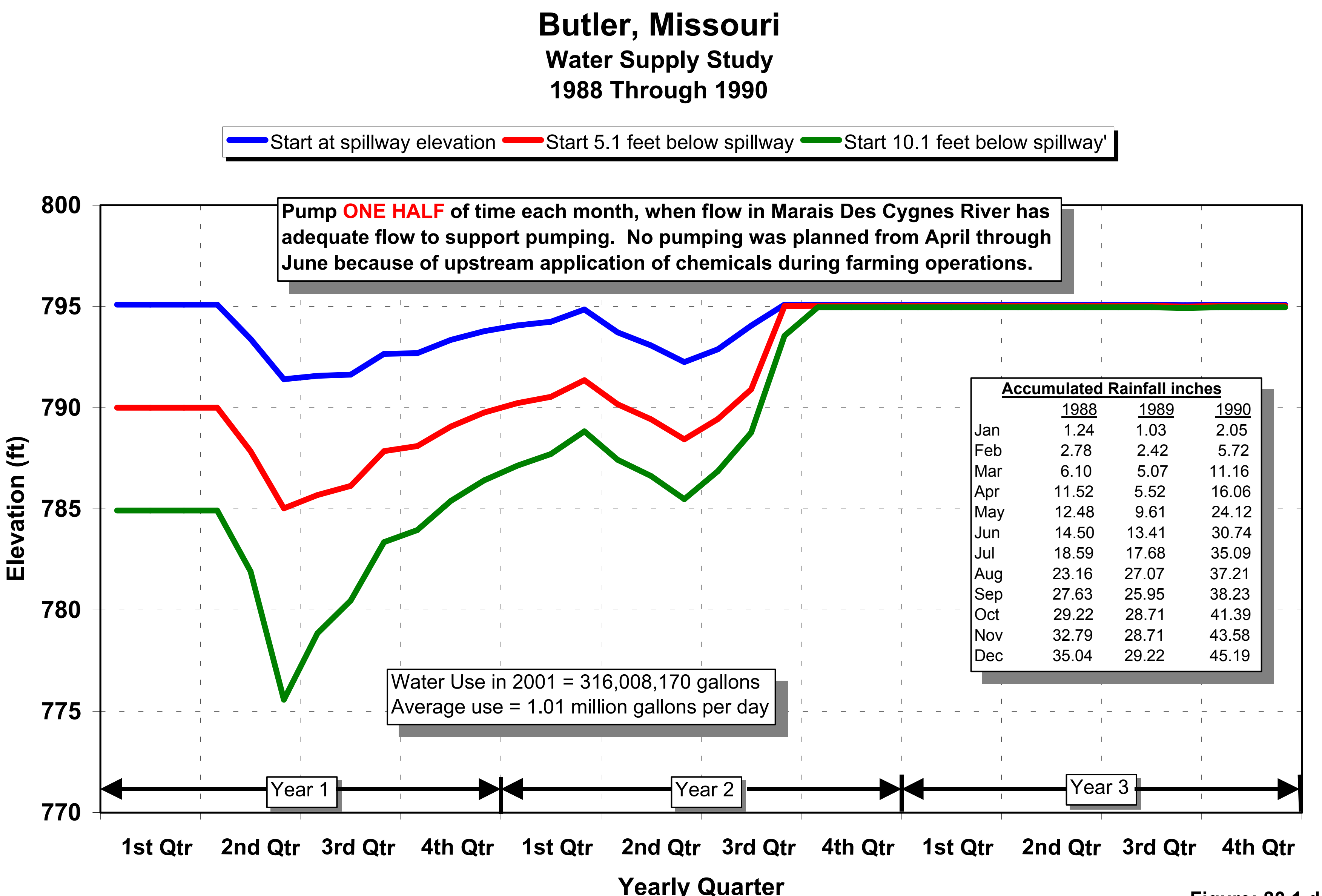

Butler, Missouri
Water Supply Study
1988 Through 1990
Start at spillway elevation
Start 5.1 feet below spillway
Start 10.1 feet below spillway'
Pump ONE HALF of time each month, when flow in Marais Des Cygnes River has adequate flow to support pumping. No pumping was planned from April through June because of upstream application of chemicals during farming operations.
Accumulated Rainfall inches
1988 1989 1990
Jan 1.24 1.03 2.05
Feb 2.78 2.42 5.72
Mar 6.10 5.07 11.16
Apr 11.52 5.52 16.06
May 12.48 9.61 24.12
Jun 14.50 13.41 30.74
Jul 18.59 17.68 35.09
Aug 23.16 27.07 37.21
Sep 27.63 25.95 38.23
Oct 29.22 28.71 41.39
Nov 32.79 28.71 43.58
Dec 35.04 29.22 45.19
Water Use in 2001 = 316,008,170 gallons
Average use = 1.01 million gallons per day
Elevation (ft)
800
795
790
785
780
775
770
Year 1
Year 2
Year 3
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
Yearly Quarter

Figure: 80.1.d

Harrison County, Missouri
Rural Water District #1 Water Supply (Eagleville)
Years 1955, 1956 and 1957

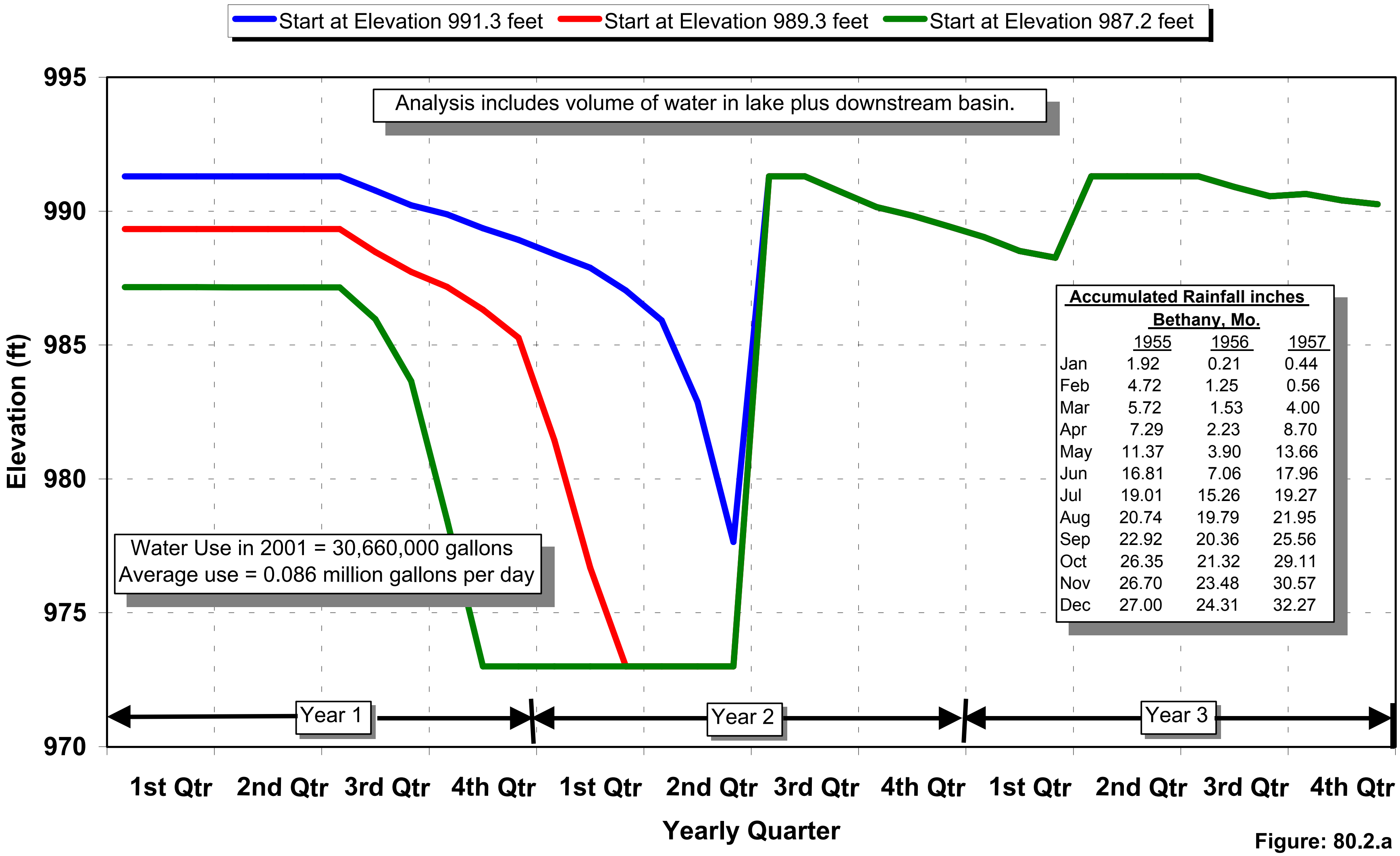


Figure: 80.2.a

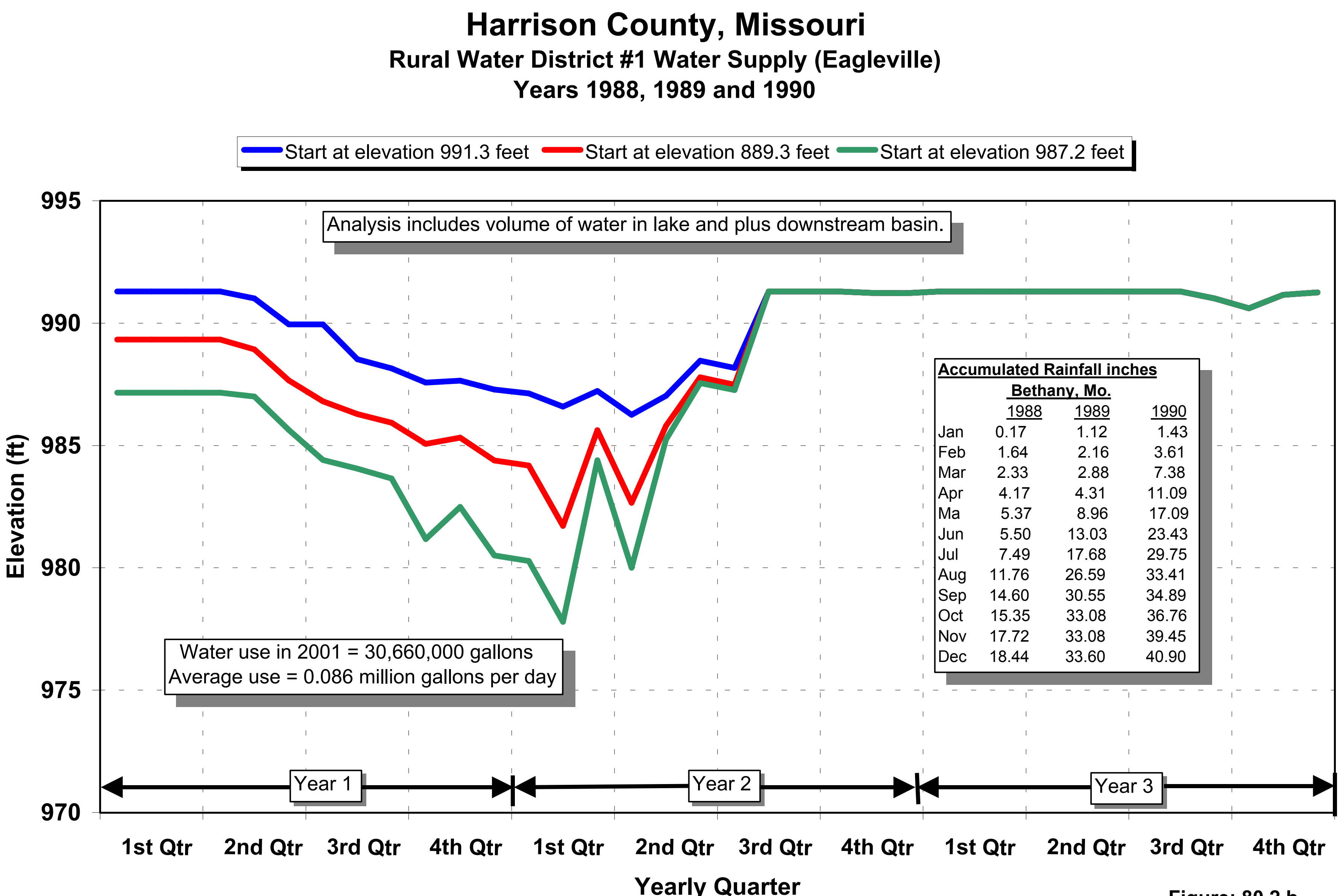

Harrison County, Missouri
Rural Water District #1 Water Supply (Eagleville)
Years 1988, 1989 and 1990
Start at elevation 991.3 feet
Start at elevation 889.3 feet
Start at elevation 987.2 feet
Analysis includes volume of water in lake and plus downstream basin.
Accumulated Rainfall inches
Bethany, Mo.
1988 1989 1990
Jan 0.17 1.12 1.43
Feb 1.64 2.16 3.61
Mar 2.33 2.88 7.38
Apr 4.17 4.31 11.09
Ma 5.37 8.96 17.09
Jun 5.50 13.03 23.43
Jul 7.49 17.68 29.75
Aug 11.76 26.59 33.41
Sep 14.60 30.55 34.89
Oct 15.35 33.08 36.76
Nov 17.72 33.08 39.45
Dec 18.44 33.60 40.90
Water use in 2001 = 30,660,000 gallons
Average use = 0.086 million gallons per day
Elevation (ft)
995
990
985
980
975
970
Year 1
Year 2
Year 3
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
Yearly Quarter

Figure: 80.2.b

Hamilton, Missouri
Water Supply
Year 1955-1958 Drought

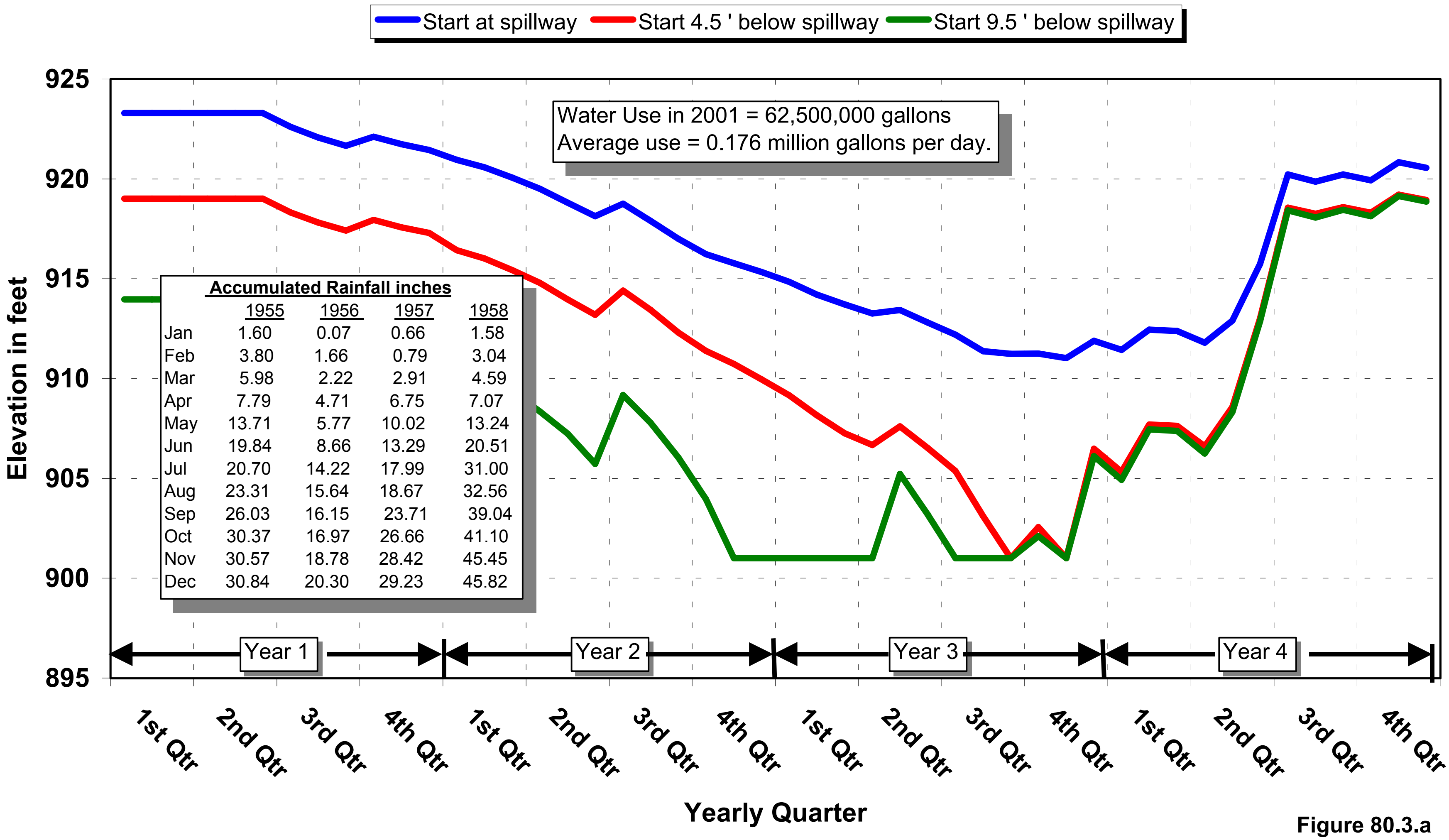


Figure 80.3.a

Hamilton, Missouri
Water Supply
Year 1988, 1989 and 1990 Drought

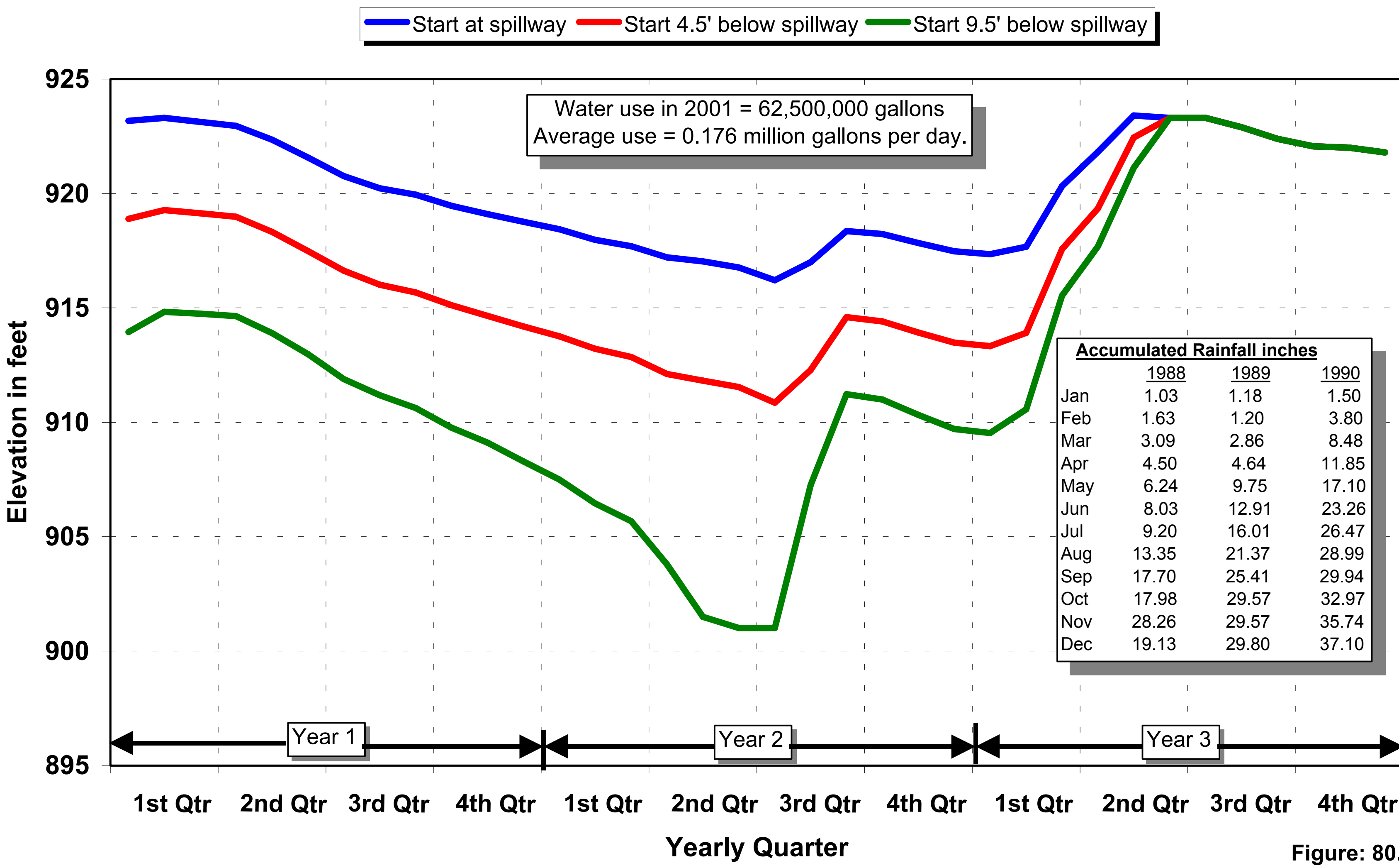


Figure: 80.3.b

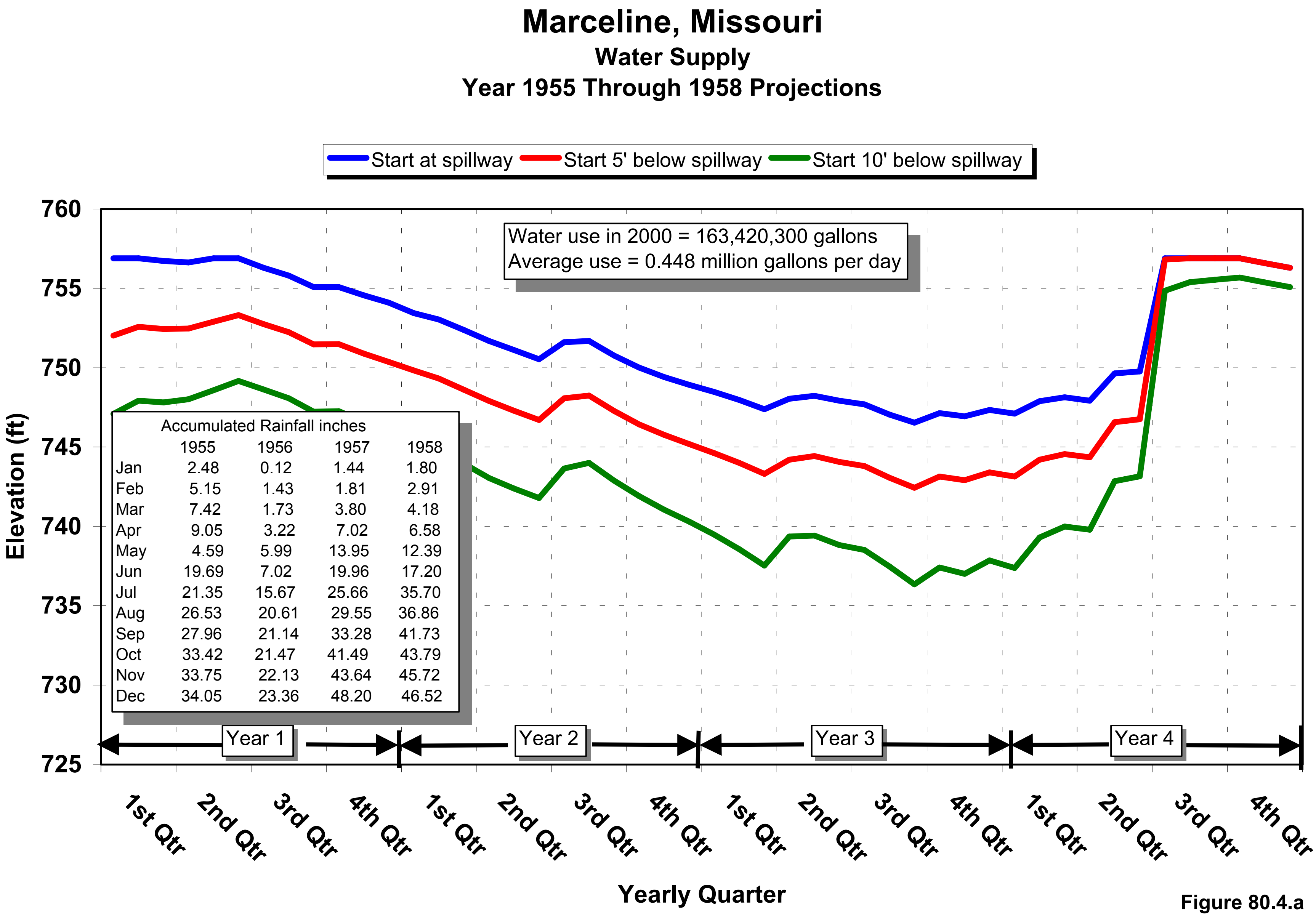
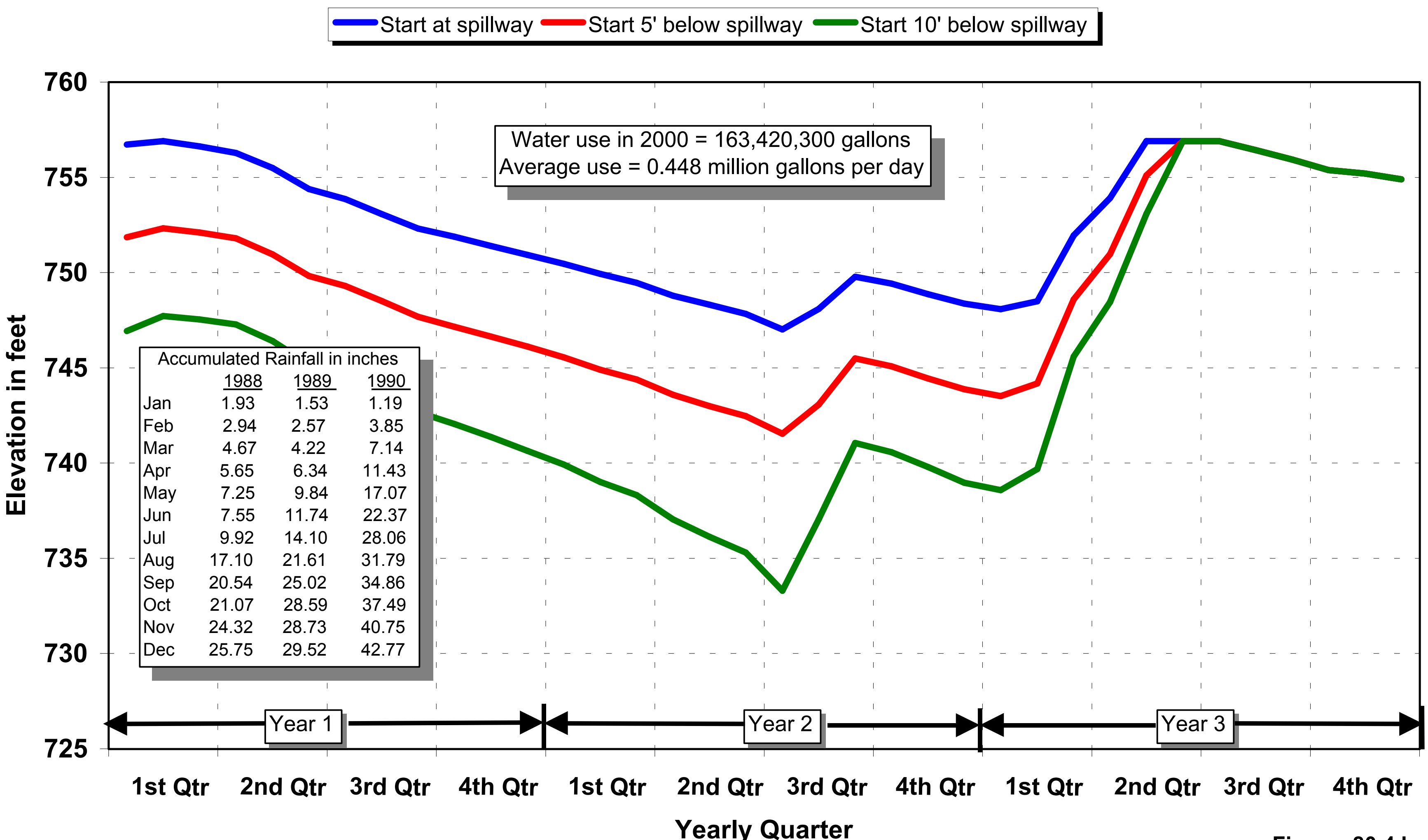

Marceline, Missouri
Water Supply
Year 1955 Through 1958 Projections
Start at spillway
Start 5' below spillway
Start 10' below spillway
Water use in 2000 = 163,420,300 gallons
Average use = 0.448 million gallons per day
Accumulated Rainfall inches
	1955	1956	1957	1958
Jan	2.48	0.12	1.44	1.80
Feb	5.15	1.43	1.81	2.91
Mar	7.42	1.73	3.80	4.18
Apr	9.05	3.22	7.02	6.58
May	4.59	5.99	13.95	12.39
Jun	19.69	7.02	19.96	17.20
Jul	21.35	15.67	25.66	35.70
Aug	26.53	20.61	29.55	36.86
Sep	27.96	21.14	33.28	41.73
Oct	33.42	21.47	41.49	43.79
Nov	33.75	22.13	43.64	45.72
Dec	34.05	23.36	48.20	46.52
Elevation (ft)
760
755
750
745
740
735
730
725
Year 1
Year 2
Year 3
Year 4
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
Yearly Quarter

Figure 80.4.a

Marceline, Missouri
Water Supply
Year 1988, 1989 and 1990 Drought



	1988	1989	1990
Jan	1.93	1.53	1.19
Feb	2.94	2.57	3.85
Mar	4.67	4.22	7.14
Apr	5.65	6.34	11.43
May	7.25	9.84	17.07
Jun	7.55	11.74	22.37
Jul	9.92	14.10	28.06
Aug	17.10	21.61	31.79
Sep	20.54	25.02	34.86
Oct	21.07	28.59	37.49
Nov	24.32	28.73	40.75
Dec	25.75	29.52	42.77

Figure: 80.4.b

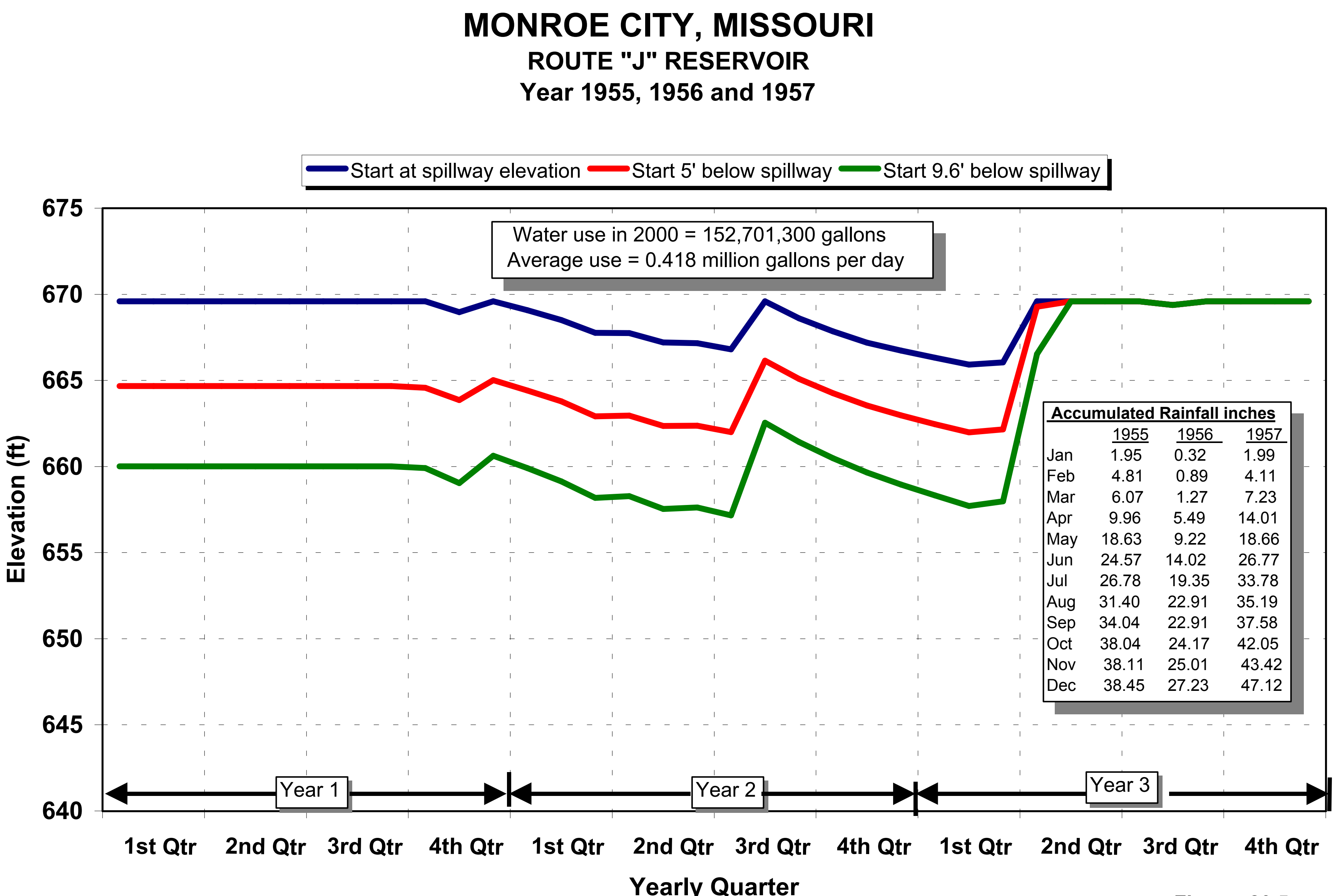

MONROE CITY, MISSOURI
ROUTE "J" RESERVOIR
Year 1955, 1956 and 1957
Start at spillway elevation
Start 5' below spillway
Start 9.6' below spillway
Water use in 2000 = 152,701,300 gallons
Average use = 0.418 million gallons per day
Accumulated Rainfall inches
1955 1956 1957
Jan 1.95 0.32 1.99
Feb 4.81 0.89 4.11
Mar 6.07 1.27 7.23
Apr 9.96 5.49 14.01
May 18.63 9.22 18.66
Jun 24.57 14.02 26.77
Jul 26.78 19.35 33.78
Aug 31.40 22.91 35.19
Sep 34.04 22.91 37.58
Oct 38.04 24.17 42.05
Nov 38.11 25.01 43.42
Dec 38.45 27.23 47.12
675
670
665
660
655
650
645
640
Elevation (ft)
Year 1
Year 2
Year 3
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
Yearly Quarter

Figure: 80.5.a

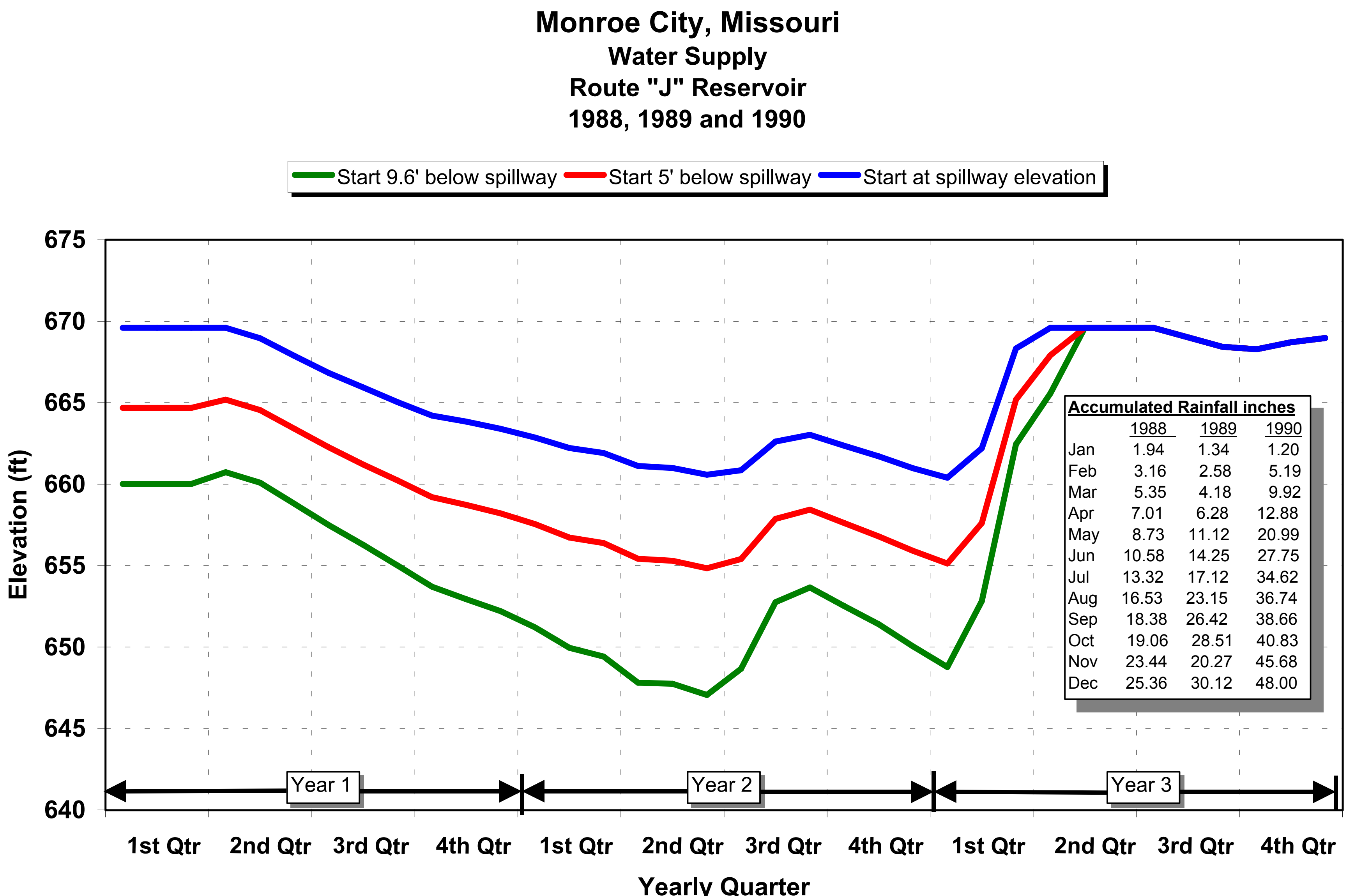

Monroe City, Missouri
Water Supply
Route "J" Reservoir
1988, 1989 and 1990
Start 9.6' below spillway
Start 5' below spillway
Start at spillway elevation
Elevation (ft)
675
670
665
660
655
650
645
640
Accumulated Rainfall inches
1988 1989 1990
Jan 1.94 1.34 1.20
Feb 3.16 2.58 5.19
Mar 5.35 4.18 9.92
Apr 7.01 6.28 12.88
May 8.73 11.12 20.99
Jun 10.58 14.25 27.75
Jul 13.32 17.12 34.62
Aug 16.53 23.15 36.74
Sep 18.38 26.42 38.66
Oct 19.06 28.51 40.83
Nov 23.44 20.27 45.68
Dec 25.36 30.12 48.00
Year 1
Year 2
Year 3
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
1st Qtr
2nd Qtr
3rd Qtr
4th Qtr
Yearly Quarter

Figure: 80.5.b

APPENDIX A

TECHNICAL RELEASE 19
DETERMINATION OF STORAGE REOUIREMENTS TO MEET WATER SUPPLY-DEMAND RELATIONSHIPS

USER MANUAL

RESERVOIR OPERATION STUDY COMPUTER PROGRAM (RESOP)

Introduction

The Reservoir Operation Study Computer Program (RESOP) can assist in the planning, design, and evaluation of reservoirs which must meet water supply and demand requirements. Reservoir operation and management has become an important issue in many areas due to increasing competition for water supplies.

RESOP will compute a monthly water balance for a reservoir system based upon inflow, outflow and reservoir storage data. The inflow minus the outflow equals the remaining storage in the reservoir. The inflow to the reservoir consists of runoff from the watershed, rainfall on the water surface of the reservoir, any outside pumping, and releases from an upstream reservoir. The outflow includes seepage, evaporation, demand and spill. The demand may consist of low flow, irrigation, municipal or other requirements. Figure A-l shows the water balance components used in RESOP. The storage data consists of a storage-surface area relation and upper' and lower limits of reservoir storage. The reservoir surface area is continuously changing as the storage in the reservoir changes. The program assumes spill occurs when the inflow minus outflow is positive and the reservoir storage is at the spill level. An estimate of seepage for each site should be made. Multiple reservoirs in series may be analyzed. Up to 50 years of reservoir operation may be computed by the program.

The RESOP program is data intensive and the mathematics are relatively simple. The advantages of using the program are that the water balance for many years may be computed quickly and any number of alternatives may be computed and compared efficiently.

Several different approaches may be used in modeling reservoir systems with RESOP. One approach is to use historical records. If the record is long enough, it may contain both wet and dry years. A range of storage limits, demands, and starting storages can be analyzed for this one period of record.

Another approach is to base all or some of the monthly input data on probabilistic analysis. This way the reservoir operation during a series of wet, dry, and normal years may be studied. Conservative evaporation values can be entered based on probability studies published in Reference 2. An example of probabilistic analysis of runoff and its effects on reservoir operation begins on page 4 of this Technical Release (TR).

More background information on reservoir operation studies is contained in pages 1 to 4 of this TR.

The remainder of this User Manual is organized into five parts, Input Requirements, Program Computations, Output Description, Sample Jobs, and Data Input Sheets.

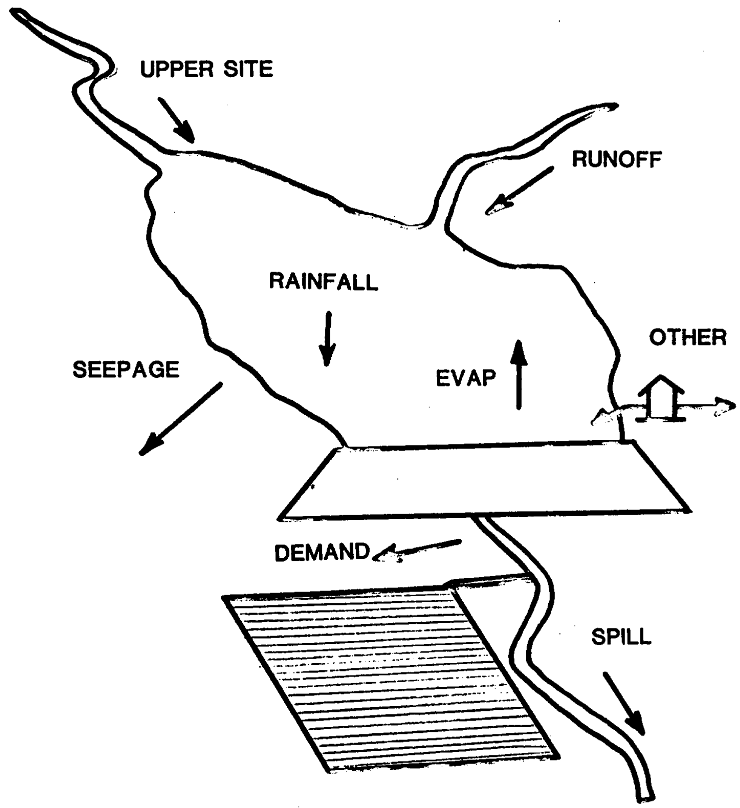


Figure A-l.--Water balance components.

Input Requirements

This program requires two types of input data. The first type is used once for each site. The second type is needed for each year of study and for each site. The program handles up to a maximum of 50 years of operation per study. All data fields should contain either alphanumeric characters or be blank. Numeric fields are not required to contain a decimal point. Input data is entered in standard 10 column fields (see input data forms and sample jobs). Each line of the record is explained by a control word. Only the first four letters of a control word are required and the word need not begin in the first column. When analyzing multiple sites, enter the data for each site in upstream to downstream order.

INPUT DATA FORM 1

CONTROL WORD

RESERVOIR First record of a job. Enter once only.

TITLE A title record is required for each operation study. This will be the information used as the heading on each output sheet. This would normally be the watershed name and type of operation, i.e., "Recreation Only", " M&I", etc. The title can contain up to 60 characters per record. Two TITLE records per job are allowed.

STO-AREA Reservoir storage-surface area curve data. Twelve (12) sets of coordinate points (acre-feet and surface area)--may be used to describe the curve; a minimum of 4 sets of points are recommended. If less than 3 points are used on the last record, the extra spaces can be left blank. Coordinate points must be shown in descending order (highest to lowest).

LIMITS Data Field 1

Upper Limit -- The storage in acre-feet representing the maximum usable or permissible storage in the reservoir, such as the top of a municipal riser or legal limit. The storage will not exceed this value. Excess water is spilled.

Data Field 2

Starting Storage -- The storage in acre-feet of the reservoir at which the study is to begin. This can be the same as the Upper Limit in urban areas and can be the same as the Lower Limit in irrigated areas. This also may depend on the starting month.

Data Field 3

Lower Limit -- The lowest storage level in acre-feet that the reservoir is to be depleted (such as the recreation pool level or the sediment pool level). Reservoir storage is permitted to go below this limit. If this happens, the deficit is printed.

Data Field 4

Drainage Area -- The uncontrolled drainage area in square miles for the reservoir under study.

GENERAL Data Field 1

Evaporation Coefficient (Annual) -- Depending on the type of evaporation data used, a different coefficient is entered.

1. If monthly Class A pan evaporation is used, enter the pan coefficient (in percent). The program will convert the pan evaporation data to free water surface (FWS) evaporation. This coefficient may be obtained from Plate 3 in Weather Bureau Technical Paper No. 37, or the more recent NWS Technical Report 33 (Reference 1).

2. If free water surface (FWS) evaporation data are used, enter 100.0 for the evaporation coefficient. FACTOR records may or may not be needed depending on significance of seasonal heat storage in the reservoir. (See FACTOR record.)

3. If actual lake evaporation data are used, enter 100.0 for the evaporation coefficient. FACTOR records should not be used.

4. If Texas Bulletin - 6006 is used for evaporation, enter the annual pan coefficient as 6XX.X where XX.X is the correct coefficient. The computer sets up a ratio of this coefficient to the value of 78.0.

Data Field 2

First Year of Record -- The calendar year in which the record begins, such as 1940. Each study may have up to 50 years of record. This value must match the first year for which data such as RUNOFF, RAINFALL, etc. is entered.

Data Field 3

Code -- Enter a "0" when no other sites above or below this site are being considered (or the field may be left blank).

Enter a "1" when spill from this site is to be saved as inflow to a lower site. Use this code for the first site of a multisite run.

Enter a "2" when spill from an upper site is to be added as inflow to this site. Use this code for the last site of a multi-site run.

Enter a "3" when both "1" and "2" apply. Use this code for any sites between the first and last sites of a multi-site run.

Data Field 4

Optimize Demand -- "0" indicates a normal run. "1" indicates that the lowest storage will be checked against the lower limit and the demand modified until the maximum demand is reached and no deficiency occurs. A "2" performs the same function as, a "1"

except all printing is suppressed until the maximum demand is found.

Data Field 5

Demand Factor -- A factor used to increase or decrease the demand (from DEMAND records) by a constant percentage may be entered. For example, if demand is to be cut in half, enter 0 .5 and if demand is to be doubled, enter 2.0. All demand values on the DEMAND records are multiplied by this factor. The Demand Factor should not be used with Optimize Demand on the same reservoir. If they are, then the demand factor is not used.

For multi-site operation studies, one site is analyzed at a time and optimize demand and demand factor may be used on different sites.

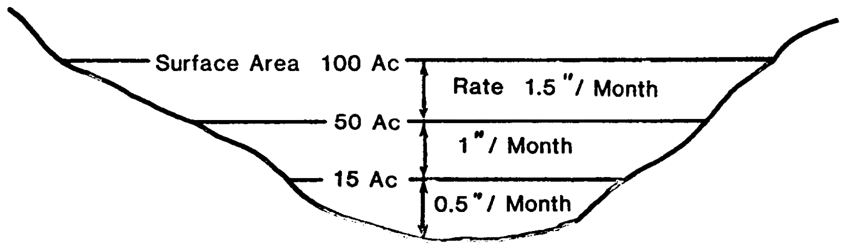
Data Field 6

Duplicate Demand -- Enter "1" and demand will be repeated for all years based on the first year of record. For example, if the same demand is desired for all years, enter a "1" in column 61-70 of the GENERAL record and enter the demand for the first year of record only.

SEEPAGE Enter up to twelve paired values of surface area in acres and a seepage rate in inches per month. Enter values in descending order. The seepage rate represents the rate between two consecutive surface area values. For example, if the surface areas of 200 acres and 100 acres are entered along with seepage rates of 1 inch/month and 0.5 inch/month, the seepage rate for all surface areas below 100 acres is 0.5 inch/month. For the area between 100 and 200 acres, the seepage rate is 1.0 inch/month. An example of seepage input is shown in Figure A-2. The program computes seepage with a similar procedure as that used in Table 2 (page 15) of this TR.

At least one pair of values must be given. The first value for surface area should be at or above that for the upper limit. If there is only one pair, the seepage rate is assumed constant. Zeros at the end of each table need not be entered.

FACTOR Use of this control word will permit entry of a monthly evaporation coefficient. Factors represent the ratio of the monthly to annual evaporation coefficient.



SEEPAGE 100 1.5 50 1 15 0.5

FOR CONSTANT RATE OF 1.5 , ENTER:

SEEPAGE 100 1.5

Figure A-2. -- Seepage rate input.

The values are multiplied by the annual evaporation coefficient entered on the GENERAL record. The result is a set of monthly evaporation coefficients. If no FACTOR records are included, the evaporation coefficient is assumed to be constant throughout the year (FACTOR values default to 1.0).

For very shallow water with negligible heat storage, the factors are 1.0. The greater the depth of the lake, the larger the fall factors and the lower the spring factors will be. Data from which monthly factors may be calculated are reported in Reference 3 for four lakes. These lakes are: Lake Okeechobee, Florida; Lake Hefner, Oklahoma; Fort Collins Reservoir, Colorado; and Lake Elsinore, California. Lake Hefner, located near Oklahoma City, has a maximum depth of approximately 85 feet, average surface area of 2,300 acres and volume of 60,000 acre-feet. Fort Collins Reservoir also has a depth of approximately 85 feet. From one to three years of evaporation data are reported for each lake. The following table of monthly factors represents the annual trend at the four lakes.

January	0.986	July	1.014
February	0.857	August	1.079
March	0.821	September	1.129
April	0.821	October	1.166
May	0.871	November	1.179
June	0.937	December	1.143

These factors are recommended for use with lakes of similar characteristics to the four lakes mentioned above. Very limited data for defining the monthly factors are available for either smaller or larger lakes.

If different factors are desired, all twelve factors must be entered on the FACTOR records. FACTOR records are not used with the Texas Bulletin 6006 procedure.

CHANGE This control word allows selected information to be modified. Enter the control word that has data to be changed (TITLE, STO-AREA, LIMITS, GENERAL, SEEPAGE, FACTOR, RAINFALL, RUNOFF, EVAP, DEMAND, OTHERIN, or OTHER). All applicable data must be re-entered following the CHANGE record. Multiple CHANGE records may be used. Data only for selected years may be changed if desired. Sample Job 4 illustrates use of the CHANGE record.

INPUT DATA FORM 2

Data on this form consists of data for each calendar year. Data for January to June is entered on the first record and July to December on the second record of each year. The data may be entered either by year or by data type. For example, enter all RAINFALL, RUNOFF, EVAP, etc., data for one year at a time, or enter all RAINFALL data, then all RUNOFF data, etc. The year is needed in columns 71 to 80 for each data type and year of record. The data should be checked by the user to make sure the data is entered by consecutive years, and each data type has values for the same years. If data for any year is missing, it is set to zero. DEMAND, OTHERIN, and OTHER data are not required for program operation. However, in most cases, the user will want to look at the effects of various demands and other inflows or outflows on the reservoir operation. END DATA and END JOB records are required.

CONTROL WORD

RAINFALL The monthly rainfall amount in inches taken from Climatological Data National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce.

RUNOFF The monthly inflow in watershed inches into the reservoir. Generally taken from USGS stream gage records. At ungaged reservoir sites, runoff data may be transferred or adjusted from a nearby gaged watershed if hydrologically similar. A source of data for runoff includes the WATSTORE system. If the mean daily flow file is retrieved at a gage, the mean monthly flow can be converted to inches over the drainage area and entered into RESOP.

EVAP Enter monthly Class A pan, free water surface, or actual lake evaporation in inches. A data source for average monthly Class A pan evaporation is Reference 2. Pan evaporation at a limited number of locations is available from Climatological data publications from NOAA.

DEMAND The monthly demand in acre-feet that the reservoir is required to satisfy. Used for municipal supply, irrigation, etc. If there is a minimum required reservoir release rate, convert the rate to acre-feet per month and add it to any other demand.

OTHER This control word may be used to input other types of inflow (positive value) or outflow (negative value) in acre-feet for the reservoir. An example would be pumped inflow.

OTHERIN As an alternative to using the OTHER record, other inflow or outflow may be entered in inches over the drainage area. The program converts this data to acre-feet of volume. Do not use OTHER and OTHERIN for the same year of record.

END DATA This control word terminates individual studies and is entered one time following the last year to be analyzed. This record lets the program know when to begin processing the data for the given site. For multiple sites an END DATA should be entered after data for each site. For various CHANGE options, END DATA should follow the changed data.

END JOB This control word may be used to separate jobs within one program execution.

END RUN After reading this control word the reservoir operation study program stops.

Program Computations

The RESOP program computes a water balance for one or more reservoirs through an accounting procedure using beginning reservoir storage, various inflows, losses, and outflows.

1. Total Inflow (TI) in acre-feet is the sum of all inflows to the reservoir for the given month. The equation used in the program is:

$$TI = (RUNOFF \times DA \times \frac{640}{12}) + (UP.\ SITE) + (OTHER) + (RAINFALL - RUNOFF) \times \frac{SURFACE}{12} \qquad \text{Eq. 1}$$

where:
RUNOFF = watershed inches;
DA = total uncontrolled drainage area in square miles above the dam;
UP. SITE = spill from upper site if present (AF);
OTHER = other inflow input by user (AF);
RAINFALL = rainfall in inches; and
SURFACE = reservoir surface area (acres) at beginning of month.

The fourth term in equation 1 represents additional water falling on the reservoir surface. Essentially all rainfall on the reservoir surface can be considered as an inflow. Runoff is subtracted because it is included in the first term.

2. A table of seepage in acre-feet per month versus surface area is calculated as shown for the example in Table 2. The seepage rate in acre-feet per month is interpolated linearly.

3. Evaporation from the reservoir surface in acre-feet for each month is computed from the equation:

$$EVAPORATION = (EVAP \times COEF \times FACTOR) \times \frac{SURFACE}{12} \qquad \text{Eq. 2a}$$

where:
EVAP = input from EVAP. records in inches for each month.
COEF = pan coefficient entered on the GENERAL record divided by 100.
FACTOR = value of monthly factor from the FACTOR records or default value.
SURFACE = reservoir surface area at beginning of month in acres.

If Texas Bulletin 6006 is used in the evaporation analysis, evaporation in acre-feet is:

$$EVAPORATION = (EVAP \times RATIO) \times \frac{SURFACE}{12} \qquad \text{Eq. 2b}$$

where:
EVAP = input from EVAP records in inches for each month.

$$RATIO = \frac{(Pan\ Coefficient/100.) - 6}{0.78}$$

The Texas Pan Coefficient entered on the GENERAL record (columns 11-20) must be greater than 600.

4. Demand is that volume of water allocated to meet the various water uses. The demand as input on the DEMAND records is not modified unless:

    A. the optimize demand option is selected or,
    B. the demand factor option is selected or,
    C. the reservoir storage is totally depleted.

    If the user desires to optimize demand, the demand will be altered by a percentage such that the reservoir storage will not drop below the lower storage limit entered on the LIMITS record. It will normally take several trials before the minimum reservoir storage falls between 1.0 to 1.05 times the lower storage limit. If the lower limit is less than 1 acre-foot, demand is changed until the minimum storage is between zero and 1 acre-foot.

    If the user desires that the demand be altered by a certain factor (demand factor option), a single reservoir operation trial will be run with demand altered (see Input Requirements, GENERAL record).

    If a certain demand will result in a dry reservoir at the end of the month, the demand is set equal to the remaining storage. The demand will increase again if sufficient inflow is available.

5. Reservoir operation monthly water balance is computed by the following equations (all units in acre-feet):

$$STO_E - STO_B + TI - SEEPAGE - EVAPORATION - DEMAND \qquad \text{Eq. 3}$$

Spill:

$$SPILL = STO_E - UPPER\ LIMIT \qquad \text{Eq. 4}$$

Deficit:

$$DEFICIT = STO_E - LOWER\ LIMIT \qquad \text{Eq. 5}$$

where:

STO_E = storage at end of month.
STO_B = storage at beginning of month.
TI = total inflow.
SEEPAGE = seepage.
EVAPORATION = evaporation.
DEMAND = demand
SPILL = outflow from reservoir.
UPPER LIMIT = upper reservoir storage limit.
DEFICIT = storage depletion below lower limit (negative value).
LOWER LIMIT = lower reservoir storage limit.

Output Description

Output from the RESOP program contains detailed information on each of the water balance aspects for each reservoir and year of operation of a job. The types of information contained in the output table and important explanation follows.

1. Month and year analyzed.
2. Rainfall in inches (repeated from input).
3. Runoff in inches (repeated from input).
4. Evaporation in inches (repeated from input).
5. Other inflow in acre-feet (repeated from input).
6. Demand in acre-feet as computed by program.
7. Up. Site in acre-feet. Spill from the upstream reservoir is considered as an additional inflow to the current reservoir.
8. Total inflow in acre-feet. See Program Computations above.
9. Seepage in acre-feet is calculated based on the surface area at the beginning of the month.
10. Surface Area in acres is the reservoir area at the end of the month. It is interpolated from the STO-AREA table input by the user based on end of the month storage.
11. Evaporation in acre-feet is the monthly evaporation based on the reservoir surface area at the beginning of the month.
12. Storage in acre-feet represents the amount of water in the reservoir at the end of the month. This value will not be greater than the upper limit of reservoir storage entered on the LIMITS record. It may fall below the lower limit if the optimize demand option is not used.
13. Deficit in acre-feet represents the difference between the end of month storage and the lower storage limit entered on the LIMITS record.
14. Spill in acre-feet represents outflow from the reservoir when the end of month storage equals the upper limit entered on the LIMITS record.

At the end of each year, totals are printed for all output except surface area and storage.

For multiple site runs and CHANGE options, similar output tables are also printed.

References

1. National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), Technical Report NWS 33, Evaporation Atlas for the Contiguous 48 United States, June 1982.

2. NOAA, NWS, Technical Report NWS 34, Mean Monthly, Seasonal, and Annual Pan Evaporation for the United States, December 1982.

3. Harheck, G.E. and F.W. Kennon, U.S. Geological Survey, Professional Paper 269, Lake Hefner Studies, Technical Report, 1954.

APPENDIX B - Estimating direct runoff from rainfall

To estimate direct runoff from rainfall, soils and antecedent moisture are considered.

This section describes adjustments to runoff based on rainfall and NRCS's runoff curve numbers (RCN). Figure 1 shows a generalized map of RCN's for the state. These RCN's were developed from stream gauge runoff data and weighted rainfall data. These numbers were then correlated with soils and land use. The most detailed discussion of RCN development is in NRCS's TR-55 (Urban Hydrology). The RCN is based on soils, vegetative cover, land use and antecedent moisture. Soil scientists have divided soils into four hydrologic soil groups (HSG's).

HSG "A" Soils have low runoff potential. Infiltration rates are greater than 0.30 inches per hour.

HSG "B" Soils have moderate infiltration rates of 0.15 to 0.30 inches per hour. These soils are silt loams or loams.

HSG "C" Soils have low infiltration rates of 0.05 to 0.15 inches per hour. These soils are Sandy clay loams.

HSG "D" Soils have very low infiltration rates of less than 0.05 inches per hour. These soils are made up of clays.

A complete list of soils with their HSG is included in NRCS's TR-55. RCN's for various land uses and crops by HSG is included in TR-55. Table 1 shows broad ranges of RCN's.

Antecedent soil moisture can be estimated by using antecedent rainfall. Adjustment to the RCN can be made to estimate direct runoff. To do this the daily rainfall values for the month are tabulated. Antecedent rainfall could extend for as much as 30 days preceding the rainfall event. Five day antecedent rainfall gives very good results and added periods of time do not necessarily give additional accuracy.

To adjust for runoff, the nearest precipitation gauge was used. Using the daily rainfall values, estimates of antecedent rainfall can be used to adjust the SCS runoff curve number for each day’s rainfall event, then added the daily runoff at the end of each month. The adjustments follow.

A Guide to Approximate Antecedent Moisture.

Total of 5-day antecedent rainfall

CONDITION	Dormant Season	Growing Season
I (Dry)	Less Than 0.5 Inch	Less than 1.4 Inch
II (Average)	0.5 to 1.1 Inch	1.4 to 2.1 Inch
III (Wet)	Over 1.1 Inch	Over 2.1 Inch

To adjust the curve number for RCN of 80. Table 10.1 of NRCS National Engineering Handbook, Part 630(Hydrology).

CONDITION	I	RCN 63
	II	RCN 80
	III	RCN 94

It is sometimes desirable to interpolate between these numbers.

	1952			1955		
Day	Mar	Anti. Moist	Run-off	Feb	Anti. Moist	Run-off
1	0.00			0.00		
2	0.33	I	0.0	0.00		
3	0.68	I	0.0	0.00		
4	0.09			0.60	I	0.03
5	0.00			0.04	I	0.0
6	0.00			0.00		
7	0.05	I	0.0	0.00		
8	0.24	I	0.0	0.00		
9	0.00			0.00		
10	0.72	I	0.0	0.10	I	0.0
11	0.00			Trace		
12	Trace			0.00		
13	0.00			0.00		
14	Trace			0.00		
15	0.07	I	0.0	0.00		
16	0.00			0.00		
17	Trace			0.00		
18	0.32	I	0.0	2.02	I	0.10
19	0.00			0.42	III	0.10
20	0.00			0.00		
21	0.22	I	0.0	0.00		
22	0.20			0.00		
23	0.00			Trace		
24	0.00			0.42	II	0.0
25	Trace			0.00		
26	0.00			0.30	II	0.0
27	0.00			0.00		
28	0.00			0.00		
29	0.00			---		
30	0.00			---		
31	0.00			---		
Total	2.92		0.0	3.90		0.23

GENERALIZED RUNOFF CURVE NUMBERS

	HYDROLOGIC SOIL GROUP A	B	C
CROPLAND			
NOT TREATED	81	88	91
TREATED	74	80	82
PASTURE			
NOT TREATED	79	86	89
TREATED	69	79	84
FOREST			
NOT TREATED	66	77	83
TREATED	55	70	77
OTHER	79	86	89

Treated is properly managed to control erosion. Cropland is terraced with waterways and residue left on ground. Pastures have good livestock rotation. Not treated is the absence of proper land use and treatment.